Aalto University
School of Engineering

Department of Engineering Design and Production
Heikki Sjöman

Learning Outcomes Through Global Product Innovation Course in Aalto University

Master's thesis submitted in partial fulfilment of the requirements for the degree of Master of Science in Technology

Espoo, May 26, 2014

Supervisor: Professor Petri Kuosmanen
Advisors: Lauri Repokari, Lic.Sc (Tech.)
Panu Kiviluoma, D.Sc (Tech.)

Aalto University
School of Engineering

Aalto University, P.O. BOX 11000, 00076 AALTO
www.aalto.fi

Abstract of master's thesis

Author Heikki Sjöman	
Title of thesis Learning Outcomes Through Global Product Innovation Course in Aalto University	
Degree programme Degree programme in Mechanical Engineering	
Major Machine Design	**Code of professorship** Kon-41
Thesis supervisor Professor Petri Kuosmanen	
Thesis advisors Lauri Repokari, Lic.Sc (Tech.) and Panu Kiviluoma, D.Sc (Tech.)	
Date 26.05.2014	**Number of pages** 70 + (22) **Language** English

Abstract

Globalisation has already profoundly affected higher education. University graduates face new multinational and interdisciplinary challenges that teaching has to address. The need behind this research lay in complexity of learning outcomes produced by such a global interdisciplinary product innovation course. The primary goal of this research was to clarify what kind of useful skills and mindsets for working life there could be gained through completing Mechanical Engineering 310 (ME310) course in Aalto University. The secondary goal was to find out and share the practical knowledge about how this kind of course is organised and taught. The ME310 is a Stanford originate interdisciplinary and multicultural course with distributed teams. It has been taught seven times in Finland during the last decade and altogether 99 Aalto students have gone through the course. The research data was collected through thematic semi-structured interviews. The informants were Finnish alumni of different classes of ME310. This research resulted in categorising the following subject areas of learning: 1. "communications - team dynamics, cross-cultural, and multiple disciplines", 2. "self–discovery - personal growth, working methods, project management, development of group work", 3. "design process (user-centric design) - prototyping, testing, decision making" and 4. "mindsets – attitude towards failing, entrepreneurship". It seemed that students go through a significant learning process during the course. The results of this study can be used, for example, as a reference point for developing degree programmes. If such methods as the ones used teaching this course are adopted in other similar courses, Aalto University's strategy: "to train broad-minded experts with a comprehensive understanding of complex subjects in order to renew technologies related to the technological industry and the built environment" could be one step closer to the reality.

Keywords Engineering Education, Aalto University, ME310, Stanford, Mechanical Engineering, product development, design thinking, problem-based learning

Aalto-yliopisto
Insinööritieteiden korkeakoulu

Aalto-yliopisto, PL 11000, 00076 AALTO
www.aalto.fi

Diplomityön tiivistelmä

Tekijä Heikki Sjöman

Työn nimi Oppimistulokset globaalilla tuoteinnovaatiokurssilla Aalto-yliopistossa

Koulutusohjelma Konetekniikan koulutusohjelma

Pääaine Koneensuunnittelu **Professuurikoodi** Kon-41

Työn valvoja Professori Petri Kuosmanen

Työn ohjaajat TkL Lauri Repokari ja TkT Panu Kiviluoma

Päivämäärä 26.05.2014 **Sivumäärä** 70 + (22) **Kieli** Englanti

Tiivistelmä

Globalisaatio on jo muuttanut korkeakoulutusta perinpohjin. Yliopistosta valmistuneet kohtaavat uusia monikansallisia ja poikkitieteellisiä haasteita, joihin opetus pyrkii vastaamaan. Oppimistulosten määrittäminen globaalilla poikkitieteellisellä tuotekehityskurssilla on kuitenkin erittäin monimutkaista. Tämän tutkimuksen ensisijaisena tarkoituksena oli selvittää, mitä työelämän kannalta mielekkäitä taitoja ja ajattelutapoja Aalto-yliopiston Mechanical Engineering 310 (ME310) -kurssilla saavutetaan. Toissijaisena tarkoituksena tutkimuksella oli selvittää ja jakaa käytännön tietoa, kuinka kurssia opetetaan. ME310 on Stanfordin yliopistosta lähtöisin oleva poikkitieteellinen ja monikansallinen kurssi, jossa työskennellään maailmalle hajautetuissa ryhmissä. Kurssia on opetettu Suomessa viimeisen vuosikymmenen aikana seitsemän kertaa ja yhteensä 99 Aalto-yliopiston opiskelijaa ovat käyneet kurssin. Tutkimuksessa käytettiin metodina temaattisia puoli-strukturoituja haastatteluita. Haastateltavat olivat suomessa opetetetun ME310 kurssin alumneja eri vuosikursseilta. Tutkimuksen tuloksena saatin neljä kategoriaa oppimistuloksia: 1. Kommunikaatio, johon sisältyi ryhmädynamiikka, monikulttuurisuus ja monitieteellisyys. 2. Itsensä kehittäminen, jossa teemoina olivat sisäinen kasvu, työskentelytavat, projektinhallinta ja ryhmätyötaitojen kehitys. 3. Tuotekehitys prosessi (käyttäjäkeskeinen tuotekehitys) ja siihen sisältyvä prototyyppien käyttö, testaus ja päätöksenteko. 4. Ajattelumallit, joista suhtautuminen virheiden tekemiseen ja yrittäjyyteen nousivat keskeisiksi. Tutkimuksen tuloksia voidaan käyttää esimerksiksi vertailukohtana, kun kehitetään koulutusohjelmia. Jos tutkimuksella selvitetyt opetusmetodit voitaisiin ottaa käyttöön muilla saman tyyppisillä kursseilla, voisi Aalto-yliopiston strategia: "kouluttaa laaja-alaisia kokonaisvaltaisesti ajattelevia asiantuntijoita, jotka pystyvät uudistamaan teknologioita teknologiateollisuuden ja rakennetun ympäristön alueilta" tulla hieman lähemmäksi toteutumistaan.

Avainsanat Insinöörikoulutus, Aalto-yliopisto, ME310, Stanford, konetekniikka, tuotekehitys, muotoiluajattelu, ongelmalähtöinen oppiminen

Acknowledgements

I am very grateful to the people I am surrounded with. People is the one thing that comes into mind while thinking about my studies. The guild of Mechanical Engineering, Aalto Design Factory, Department of Engineering Design and Production, University of Exeter and ADDLAB are full of amazing individuals. I owe never-ending gratitude to so many people that it is hard to imagine. Professor Petri Kuosmanen was the person who eight years ago suggested that I take Machine design as my major subject in the Helsinki University of Technology, and now consequently acts as a supervisor for my Master's thesis in Aalto University. Thank you Lauri Repokari for accepting me to the ME310 course and providing excellent teaching, changing the direction of my life, and now advising me on this thesis. Thank you Panu Kiviluoma for providing a scientific approach to my thesis.

The best things happen in the best company. Thank you Hanna, Kristiina, Emma, Taru, Päivi, Ville, Joona, Mikael, and so many others for helping, discussing, proofreading, doing the layout, and especially supporting me during this last effort of my university life as a student. I am sure that I do not exaggerate if I write that I would not be here without you.

You are super-important! Greetings to mom, dad and the rest of the family!

26th of May 2014, Helsinki

Heikki Sjöman

Table of Contents

List of Figures

List of Tables

Commonly Used Terms and Abbreviations

Aalto = Aalto University

ADF = Aalto Design Factory

Creativity = Connecting and re-arranging of knowledge to generate new, often surprising ideas that others judge to be useful

EXPE = Final gala of the course held at EXPE design fair in Stanford

IDBM = International Design Business Management master's program taught in Aalto University

Idea = A plan or purpose of action; intention; design generated from existi ng information combined in a novel way

ILO = Intended Learning Outcome

LGM = Large Group Meeting

ME310 = Mechanical Engineering 310

Problem = Any situation in which a gap is perceived to exist between what is and what should be

Problem Space = A mental representation of a particular problem, including initial, final and possible intermediate states

Prototype = A play, anything, an early sample or model built to test or communicate a concept or process

PBL = Problem-based learning

SDL = Self Directed Learning, a part of Problem-based learning methodology

SGM = Small Group Meeting

Solution Space = A mental representation of a particular set of solutions, including initial, final and possible intermediate states

TA = Teaching Assistant

1 Introduction

1.1 Background

Globalisation, the reality of the 21st century, has already profoundly affected higher education. In this research, I am concerned with how globalisation affects what should we learn in universities. Altbach defines globalisation as the reality shaped by an increasingly integrated world economy, new information and communications technology, the emergence of an international knowledge network, the role of the English language, and other forces beyond the control of academic institutions [1]. Some decades ago it was enough that a graduate student went through formal education and the employer taught the rest. Nowadays, the needs of employers and the wider economy have produced increased emphasis on **employability** skills, **entrepreneurship** and the need for **internationalisation** to enable graduates to work in the global economy [2]. That is why universities have to compensate this need by introducing **new methods of teaching** [1]. But how to know what kind of teaching is required for the jobs that do not exist yet? The underlying assumption in this study is that there is a need for more problem-based learning and system level engineering in interdisciplinary teams.

An interesting place to start the search is within the Stanford global product innovation course Mechanical Engineering 310 (later ME310). The course has been taught in Finland for almost a decade. ME310 predates IDEO and uses a related version of the Design Thinking paradigm. It combines DT processes with formal project-oriented and product-based learning pedagogy. The core idea is that “reality is the best teacher” and the “best teacher is a coach.” ME310 engineering design teams take-on real world design challenges from multinational corporate sponsors. Small (3-4 member) Stanford graduate student teams work with comparable teams at other universities across the planet. The course is said to be educating the best possible new-product-managers (NPM) in the world and that makes for a reputation [3]. Do students learn something extraordinary during the course which makes them more prepared for the challenges of the complex and globalised world of today?

Problem-based learning (PBL) has been around since the 1960s [2]. The core of PBL is the belief that contextual, student-centric, and active learning is the most effective and stimulating way to learn. PBL has been a natural solution in education since professional training began to transfer into educational institutions. Consequently, reforming engineering education towards the context of real-world demands, and PBL are necessary for aligning engineering education with the career paths of engineering graduates. [4][5] This might be easier to say than do, and that is why this study also focuses on sharing practical knowledge of the teaching pedagogy. This should be useful for universities joining to teach ME310, and for those who teach similar advanced courses.

Some extra local value to this study is given through the revelation in the Teaching and Education Evaluation (TEE) report [6] produced in Aalto University during 2010-2011, which says among other things that students are not understanding the learning objectives of their studies in science and technology. For example, according to the report, the intended learning objectives are clear to 65% of mechanical engineering students after completing a course and 28% of students after completing the master's programs. Problem-based learning is not the easiest way to study or to teach and definitely not the easiest to define the learning outcomes. That is partly why this stydy has been written. This study tries to shed light on one of the goals of the TEE report, namely, making objectives more clear for the students. It seems that students that go through the course change significantly during the process, but before this thesis it has not been made explicit how and why this occurs.

1.2 Research Questions and Scope

The objective of this study is to shed light and provide solid themes of what students actually learn on the ME310 course in Finland. The learning outcomes are extracted, validated and supported by alumni interviews where alumni tell about their experiences during and after the course and compare their attitudes and relevant learning during the course to their colleagues in working life after the course.

The main focus is the global product innovation course ME310 at Aalto University. The scope is framed by the following research questions:

1. **What are the actual learning outcomes of the ME310 course in Aalto context validated by alumni experience?**

2. **What are the best practices of the course to offer for other similar courses in pedagogical terms?**

This study also compares the learning experience of prospective students expectations interpreted by the teaching team of the class 2013 to the intended learning outcomes developed based on the results of this study, and thus helps to understand how the intended learning objectives correspond to the perceived ones.

While this study's analysis may be illuminating, several limitations in the data are important to recognise. All survey and interview responses are self-reported, and older memories are subject to the vagaries of time. Moreover, the survey sample is not statistically significant, nor does it accurately represent the entire population of ME310.

Another interesting possibility left out of the scope of this study is that the researcher is not comparing data to the interviews of students that have gone through different product development courses. In addition, what is left outside the focus of the present study is the investigation of how the selection process advances the learning outcomes. The researcher has completed the course and gone through its process, so it could potentially affect the analysis of the research results as it could have been subconsciously filtered by the researcher's preliminary thoughts of the outcomes and experience of the course. This phenomenon is impossible to avoid in this kind of research setting.

1.3 Methods: Semi-structured Interview

The method chosen for this research is semi-structured thematic interviews. The interviews are targeted for fifteen alumni of different classes in the history of ME310 in Finland. A pre-questionnaire was used to discover the themes for the interviews.

1.4 Structure of the Thesis

This work is divided into six sections. The first (1st) section introduces the problem and its background and deals with the research questions and limitations of the study. The second (2nd) section provides a review of the latest literature of design thinking, problem-based learning and teamwork. The first part of the third (3rd) section 'materials' maps out the structure and ideas behind the course pedagogics. Purpose of this section is to give context for the best practices recommended. The second part 'methods' explains the research method of the semi-structured interviews in detail. The fourth (4th) section 'Results' provides the most important findings of the research and the analysis of all the interviews with illustrating quotations. The fifth (5th) section discusses the implications of the results and reflects the findings against the theory reviewed. The sixth (6th) section concludes the thesis and summaries the key findings and their significance.

2 Literature Review

Consulting companies like IDEO and Frog Design have achieved notable success in a wide variety of industries through the use of adaptive design thinking and semi-formal use of a “coaching” model that has some members of each development team explicitly focused on the team’s behaviour pattern with an eye to focusing activity on the critical tasks from a system integration point of view. ME310 course is partly based on the ideology of these companies. [101]

This section introduces the main theories of design thinking, project-oriented and problem-based learning and teamwork that will allow the reader to better understand the theoretical background of the ME310 course. Since the secondary goal of this study is to produce more precise and clear learning outcomes, also the theoretical framework for SOLO and BLOOM taxonomies are explained to give context for the later work.

2.1 Design thinking

When discussing product development the term ‘design thinking’ is often mentioned and discussed, and it is seen as a way of thinking that can significantly enhance the design process and the outcomes of it [19]. No shared definition seems to exist on what design thinking is and what it consists of [20], but most authors agree that design thinking is a way of solving problems that consists of thinking and acting that together lead to new surprising outcomes [e.g. 21]. According to Simon [22], design thinking is a process consisting of seven stages; defining the problem, researching, ideating, prototyping, choosing, implementing and learning. More recent studies show that design thinking is not only a set of actions, but also a combination of practices and cognitive approaches as well as a mindset [e.g. 23]. Two perspectives on design thinking can be identified: ‘design discourse’ and ‘management discourse’ [24]. The former more focused on design methodology and cognitive processes [25,26,27,21] and the latter on creating innovation and value [e.g. 28,29].

As literature suggests, tolerating failure and embracing risks and wild risks will provide foundation for radical innovations that the ME310 is after [30]. User centric-design is all about the user. It is necessary to go beyond asking your clients since the answers might be skewed, because of politeness or simply because clients do not have the vocabulary to tell you what is missing or wrong with your product [30]. This was well understood in the answers of the alumni.

IDEO has some focus points in their own development of work and observing techniques are key. They think that it is really important to build empathy towards your user. By observing the user’s handicaps, you can see a lot of hidden needs that people do not necessarily identify. You learn the most from people who break the rules since they are those who think about shortcuts and “what if” questions [30]. The human factor is always present, but not always so predictable since people for example might not jump to different solutions from the previous ones. This is something to consider when looking for commercially viable solutions. Kelley continues with some techniques such as looking at your user in motion and using verbs to describe their actions to find non-trivial solutions to problems. In addition to the techniques, many organisations do not understand that they could brainstorm more frequently and better. They claim to do so, but when comparing this to IDEO practices, it seems that their brainstorming is elevated to the level of a religion almost. It is not just the number of brainstorms practiced, but how and who does it and where.

The problems solved using design thinking processes and methods are often complex and loosely formulated, open-ended problems to which there is no one correct answer [31]. These kinds of tasks, that are also called wicked problems [31, 32] or system problems, require a holistic way of solving that produces systemic, holistic solutions [33, 34, 35], thus traditional ways of searching for solutions are often too straight forward. University students need to acquire thinking and working skills to tackle these kinds of wicked challenges, but their education often leaves them under equipped to do so [36].

Depending on the source, there are many ways of describing the characteristics of the cognitive process, which is at the core of design thinking. Some describe it as abductive [29,37], some integrative [26,28] or divergent balanced by convergent thinking [26,28]. All these emphasise the importance of creating multiple new solutions to choose from instead of choosing from existing alternatives or creating only one solution to a problem [26,29,28]. Thus the explorative content of design thinking emerges already at a cognitive level [19]. The main idea is to look at what actually happens, not act based on assumed facts.

Teams are the heart of the IDEO method, on purpose. Great teams having a clear goal and a serious deadline achieve great results. To back this up, there is a lot of evidence from psychology research how group processes and dynamics work. [30] Haslam states that social identity salience impacts upon a group’s willingness to maintain commitment to an organisational project relevant to its identity. [39] It is unclear what the impact of social identity salience to the initial commitment and enthusiasm for a project is. He found clear evidence that as an organisational project, which groups have previously championed, begins to encounter difficulties, groups whose members have a heightened sense of shared social identity are much more likely to remain committed—attitudinally and resourcefully—to their initial decision to support that project than those whose members are individuated. [39] This fits to the ME310 course pedagogy by making a constant effort to create social identity for the student group.

Mindset and attitude towards problem solving and practices also play an important role in design thinking. It can be described as explorational and experimental activity [33] that has a continual character [26,33] to it. One of the most important tools for experimenting and searching for solutions is prototyping [28] in various ways and from early on. One aspect that surfaces in various sources is user-centricity [e.g. 33,34,37] and therefore testing ones ideas and prototypes with users can be stated to be of importance as well. The outcome of experimenting and going through rounds of trial and error should be learning and identifying directions for the process – which might not have been taken otherwise – while aiming for a significantly new solution to a problem by questioning what is already known [33]. Therefore, the nature of solving open-ended problems requires disregarding the fear of failure [34], acceptance of ambiguity [25,37] as well as the ability to reflect in action [21].

2.2 Project-oriented and Problem-Based learning

In this chapter the theory base of project-oriented and problem-based learning (POPBL) is discussed and explained in detail: how the combination of methods works and what to achieve by using this approach. The goals and challenges of this teaching approach are elaborated individually later in this section. Theory also reviews critically when it is appropriate to use this strategy of teaching.

> *"Induction is the natural human learning style. Babies do not come into life with a set of general principles but rather observe the world around them and draw inferences: "If I throw my bottle and scream loudly, someone eventually shows up." Most of what we learn on our own (as opposed to in class) originates in a real situation or problem that needs to be addressed and solved, not in a general principle; deduction may be part of the solution process but it is never the entire process." [40]*

We live in a world where systems gradually become larger, and the boundaries for engineering knowledge and skills are increasingly more difficult to identify and define [42]. It is more and more important that engineers master a combination of disparate capabilities – not only technical competencies concerning problem solving and the production and innovation of technology, but also interdisciplinary skills of cooperation, communication, project management and lifelong learning abilities in diverse social, cultural and globalised contexts. It is also suggested that engineers should develop a broad perspective of social, environmental and economic issues. [42] At the same time engineers must excel in the actual engineering competencies [43,44].

As a strategy for educational development, project-oriented and problem-based learning (POPBL) provides a possible answer to these challenges. Thereby, POPBL provides the students with the possibility of achieving sustainable and transferable skills, while at the same time exposing them to the complexities of global and cultural issues [45]. Skills and competencies are developed while students work in teams and though process students discover much about themselves, thus giving a more realistic view about their own self-image. The methodology cultivates a spirit of investigation and innovation, creativity for the generation of new knowledge, productive thought, and motivation to learn and solve problems. [46]. The POPBL is a larger and more general genre of education where different frameworks can be applied.

In Problem Based Learning (PBL), a framework of educating students through problems, the students build their own knowledge by active learning, interacting with the environment as suggested by the constructivist approach, working independently or collaborating in teams, while the teacher directs and guides and they make a real product. PBL is also helpful for developing long-term learning skills. It offers multiple possibilities for developing technical, contextual and behavioural competences. [47] Throughout the different phases the scientific basis of project-based learning is maintained to generate learning processes in which students are not passive recipients of knowledge, but are immersed in a pre-professional experience [47].

In PBL learners develop deep, integrated understanding of content and process [48]. Furthermore, teamwork is embraced to tackle problems where the collaboration plays an important role in a form of sharing ideas of how to proceed and what to try. According to Krajcik et al. in order to succeed in the real world, students need a multidisciplinary approach and to know how to operate in such an environment. PBL offers a great deal of responsibility to students for their own learning and actively involves them in various tasks. This enables various ways of learning, which serve different types of students. [47,48]

2.2.1 Challenges

Teaching by means of PBL or with PBL-style presents several challenges for the teacher. These include: teachers' content knowledge, students' lack of experience in this new approach and their preference for traditional-structured approach, students' preference for a learning environment which would require less effort on their part, and problems arising from time stress. [46] The theory suggests that qualities of the skills learned through PBL are:

“1. Acquisition of knowledge that can be retrieved and used in a professional setting

2. Acquisition of skills to extend and improve one’s own knowledge

3. Acquisition of professional problem-solving skills

Cognitive psychology sees that learning is active an process of constructing and deconstructing knowledge and PBL is consistent which these findings. Knowledge is structured in interrelated networks of concepts. Both higher degree of detail and a higher density of relationships between these nodes makes the information more useful and transferable.” [49]

At the same time, the theory stresses that the PBL approach requires that both teachers and students should adopt a more active role, greater shared commitment, and in the particular case of the students, greater responsibility for their own learning. Throughout the different phases the scientific basis of project-based learning is maintained to generate learning processes in which students are required to integrate the knowledge they have already gained from other courses with new knowledge attained in developing the project. [46]

2.2.2 Learning Outcomes

Working life skills are also developed: communication, leadership, commitment and motivation, self-control, self-confidence, openness, creativity, outcome orientation, efficiency, values, and the capacity for adaptation and innovation in problem solving. The theory suggests that welcoming in clients from outside the university might show new results of learning, since it opens up new space for educational innovation through project work that enables us to link the professional to the educational world. [46]

The setting of the methodology in problem-based learning (PBL) is that students learn through facilitated problem solving. It is normal for PBL to center learning around an ill-defined problem setting. Students are encouraged to take responsibility themselves and try to find and decide what is the required information for each problem. They engage in self-directed learning (SDL) and then apply their new knowledge to the problem and reflect on what they learned and the effectiveness of the strategies employed. The teacher acts to facilitate the learning process rather than to provide knowledge. According to another study, the goals of PBL include helping students develop 1) flexible knowledge, 2) effective problem-solving skills, 3) SDL skills, 4) effective collaboration skills, and 5) intrinsic motivation. [50]

The evidence suggests that “PBL is an instructional approach that offers the potential to help students develop flexible understanding and lifelong learning skills. PBL is well suited to helping students become active learners because it situates learning in real-world problems and makes students responsible for their learning.” [50]

2.2.3 Process and Goals

The method in PBL is to work in small groups collaboratively and delve deep into the heart of the problem. Students try to define for themselves what is relevant for each problem and extract specific knowledge on that area. In this context, the teacher acts as a facilitator to guide students through the learning cycle depicted in Figure 1. In PBL, the process where the problem scenario is presented for students is called the tutorial process. They formulate and analyse the problem by identifying the relevant facts from the scenario. This fact-identification step helps students recreate and present the problem. As students understand the problem better, they generate hypotheses about possible solutions. Hereafter they do some reflection about what the gist of the problem is and where the knowledge deficiencies of the group lie. These become the learning issues that the students research during their self-directed learning phase (SDL). Following SDL, students apply their new knowledge to their hypotheses in light of what they have learned (in the form of prototyping in ME310). Once each problem has been completed, students reflect on the abstract knowledge gained.

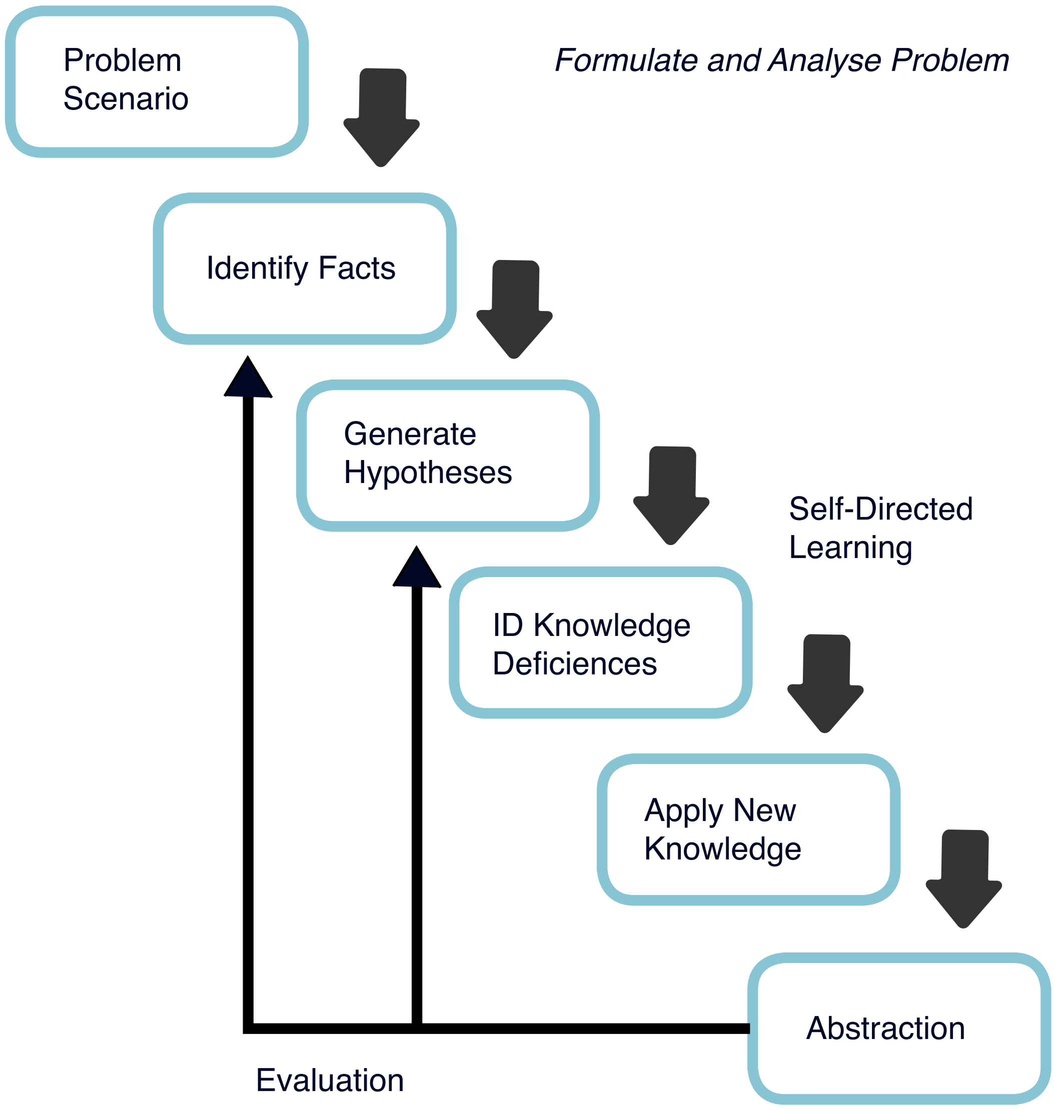

Figure 1 The problem-based learning cycle. (Hmelo-Silver, Cindy E., 2004.) [50]

In PBL, students become responsible for their own learning, which necessitates reflective, critical thinking about what is being learned [51, 52]. In PBL, students are asked to put their knowledge into practice and to be reflective and self-directed learners. [50]

The purpose of discussing problems in a PBL group (before beginning to research learning issues) is to activate relevant prior knowledge and facilitate the processing of new information [53]. Students are better able to construct new knowledge when they can relate it to what they already know [54]. [55]

Achieving the second goal, the development of effective problem-solving skills, requires the ability to apply appropriate metacognitive and reasoning strategies. [56] This means planning one's problem solving, monitoring one's progress, and evaluating whether one's goals have been met [57].

Metacognitive strategies are also important for the third goal of developing self-directed, lifelong learning skills. These are the skills that enable autonomous learning. There are several sub-skills involved in SDL [58,59]. First, learners must have a metacognitive awareness of what they do and do not understand. Second, they must be able to set learning goals, identifying what they need to learn more about for the task they are engaged in. Third, they must be able to plan their learning and select appropriate learning strategies. Finally, learners must be able to monitor and evaluate whether or not their goals have been attained. All these steps utilise learning skills and contribute to being a better learner. SDL is discussed in more detail after two sections later.

The fourth goal of being a good collaborator is to know how to function well as part of a team. This encompasses establishing common ground among disciplines and individuals, resolving discrepancies, negotiating the actions that a group decides to take, and coming to an agreement [60]. These tasks require an open exchange of ideas and engagement by all members of the group [61][62]. Explaining one's ideas is important for productive collaboration and also serves to enhance learning [63]. In ME310 pedagogy, prototyping is used in this phase to explain and express ideas. The goal of becoming a good collaborator and the process of learning collaboratively are often woven together. In PBL, students are encouraged to attend to collaboration processes through their reflection and through the interdependence of learning within the group, but they do not necessarily know how to deal with the collaborative aspects of PBL effectively [64][65].

The final goal of PBL is to help students become intrinsically motivated. Intrinsic motivation occurs when learners work on a task motivated by their own interests, challenges, or sense of satisfaction. Homogenous and high achiever groups are easier in this sense since the problem can be picked to support the students. Several features of PBL support increased motivation for learning. Students are more motivated when they value what they are learning and when their educational activity is implicated in personally meaningful tasks [66][67]. Students are also more motivated when they believe that the outcome of learning is under their control [68][69]. Proximal and tangible goal of applying their knowledge should be provided to solve a concrete problem in order students to become intrinsically motivated [68].

Classroom contexts that reward students for deep understanding, independent thought, and action are also more motivating than many traditional classroom structures that reward comparative performances [70,71,72]. PBL instruction techniques assume that all these goals are achieved as part of the PBL learning cycle.

At several points during their problem solving, students typically pause to reflect on the data they have collected so far, generate questions about that data, and hypothesise about underlying causal mechanisms that might help explain the data. Students also identify concepts they need to learn more about in order to solve the problem, labelling these concepts as "learning issues." After considering the problem with their naïve knowledge, students independently research the learning issues they have chosen. They then regroup to share what they have learned, reconsider their hypotheses, and/or generate new hypotheses in light of their new learning. When completing the task, learners deliberately reflect on the problem to abstract the lessons learned about the problem and about their SDL and collaborative problem-solving processes.

2.2.4 Designing Problems

Cognitive research and practical experience with PBL have made important strides in identifying the characteristics of a good problem [57,73,74]. To foster flexible thinking, problems need to be complex, ill-structured, and open-ended. In order to support intrinsic motivation, they must also be realistic and resonate with the students' experiences.

Good problems in a PBL context often require multidisciplinary solutions. The necessity of gathering knowledge from a wide range of sources allows students to see how knowledge is a useful tool for problem solving. Good problems also foster communication skills as students present their plans to the rest of their class. Multidisciplinary problems should help build extensive and flexible knowledge because information is not learned in isolation. [50]

The research demonstrates that as people are first attempting to apply new knowledge, they do not always do it well [75][76]. Theory suggests that errors are a necessary step in learning to apply new knowledge. By articulating incorrect knowledge, learners have the opportunity to revise their false beliefs when they are confronted with correct knowledge. The research suggests an advantage in having a well elaborated knowledge structure that contains some errors, instead of having little elaborated knowledge that cannot be applied. [77]

When comparing gifted students who were traditionally instructed with students in a PBL class on problem-solving skills, in one study it was found that PBL students were more likely to include problem finding as a step when presented with a novel ill-structured problem. [72] Although research on the influence of PBL on strategy transfer is limited, it does provide some evidence that students in PBL learn problem-solving and reasoning strategies that are transferable to new problems. [50]

2.2.5 Facilitating

Having good problems is a necessary but not sufficient condition for effective PBL. The facilitator role is critical to make PBL function well.

According to theory, the teacher/facilitator of PBL is an expert learner, able to model good strategies for learning and thinking, rather than an expert in the content itself. The facilitator scaffolds student learning through modelling and coaching, primarily through the use of questioning strategies. [80] Facilitators progressively remove their scaffolding as students become more experienced with PBL, until finally the learners adopt many of the facilitators' roles. The facilitator is responsible both for moving the students through the various stages of PBL and for monitoring the group process. This monitoring ensures that all students are involved and encourages them both to externalise their own thinking and to comment on each other's thinking [81][82]. The PBL facilitator first guides the development of higher order thinking skills by encouraging students to justify their thinking and second externalises self-reflection by directing appropriate questions to individuals. The facilitator plays an important role in modelling the problem solving and SDL skills needed for self-assessing one's reasoning and understanding. Although the facilitator lowers some of his or her scaffolding as the group gains experience with the PBL method, she or he continues to monitor the group, making moment-to-moment decisions about how best to facilitate the PBL process. The facilitator directly supports several of the goals of PBL. First, she or he models the problem solving and SDL processes. Second, they help students learn to collaborate well. An underlying assumption is that when facilitators support the learning and collaboration processes, students are better able to construct flexible knowledge.

Facilitation is a subtle skill. It involves knowing when an appropriate question is called for, when the students are going off-track, and when the PBL process has stalled. In a study of an expert PBL facilitator, [65] found that he accomplished his role largely through metacognitive questioning and questions that focused students' attention and elicited causal explanations. In this study, the facilitator used a variety of strategies to support his goal of getting medical students to construct causal models of a patient's illness. He asked students to explain their reasoning to the point where they realised that the limitations of their knowledge necessitated creating a learning issue. Another strategy was to ask students how hypotheses related to the patient's signs and symptoms in order to encourage the students to elaborate on causal mechanisms. This study demonstrated that an expert facilitator has a flexible set of strategies that can be tailored to different stages of the PBL process.

An important issue in moving beyond this model of PBL is one of scale. The role of the facilitator is extremely important in modelling thinking skills and providing support. In one study, the medical school environment was privileged in being able to provide a facilitator for each small group. It is less clear how this might translate into other environments. [83] The researcher of that study were successfully managed to facilitate multiple groups, using a wandering facilitation model. In this model, the facilitator rotates from group to group, adjusting the time spent with each of the groups in the classroom according to their needs. By looking at large poster sheets created by each group and hung on the classroom walls, she was able to dynamically assess the progress of each of the groups and adjust her facilitation efforts accordingly. In addition, students rotated through the facilitator role with the help of prompt cards that gave examples of different techniques that could be used at different stages of the PBL process. This is a lower level of scaffolding than is possible in a one-facilitator-per-group model so some adaptations of PBL are needed to accomplish some of the facilitation functions. For example, reflection rarely happens in groups without a facilitator and so alternative mechanisms, such as structured journals, are needed to ensure reflection [80].

2.2.6 Self-directed Learning

One of the purported benefits of PBL is its claim to prepare life-long learners because of its emphasis on self-directed learning (SDL). We can see what it means to become a self-directed learner by reviewing qualitative studies of SDL, specifically reviews of the literature that examines quantitative indicators of SDL. Some of the indicators of SDL include planning one's own learning, developing and applying strategies, and appropriately using learning resources

Becoming a self-directed learner is a multidimensional process. When students in PBL curricula in three different disciplines were interviewed, Dahlgren, Abrandt and Dahlgren found that students in two of three disciplines felt a great sense of uncertainty about what to study. [84]

The first analysis used a grounded theory approach and focused on two of these students as it examined the interactions of academic self-concept, learning strategies, learning opportunities provided by the program, and evaluation mechanisms [85]. Both students developed strategies for coping with challenges to their self-efficacy and described the reflection on their learning and information-seeking strategies. This research provides a glimpse into the lives of two students learning to adapt to the SDL demands of a PBL program.

For students who are poor self-regulated learners, PBL is likely to pose difficulties without appropriate scaffolding for students trying to develop SDL skills. Becoming self-directed learners is not a given as the Evensen et al. and Ertmer et al. studies demonstrate. [86][87]

2.2.7 Project-based Learning as a Strategy for Education

Enhancing student motivation is purported to be a major advantage of PBL. Because learning issues arise from the problem (in response to students' need to know), intrinsic motivation should be enhanced. Unfortunately there is little research that bears directly on this issue. Most of the research has instead examined student satisfaction or confidence. Students' reaction to a PBL course in statistical reasoning was mixed [88]. Some students really enjoyed the class, but others resisted changing their way of learning or did not like working collaboratively.

It is important to note that in medical schools, the students are a fairly select group and the PBL curricula are well established. Moreover, PBL is used throughout the entire curriculum. In other studies, the instructional intervention was a single experimental course within a larger curriculum with competing demands from other well-structured courses. A single course may not provide the opportunity to become acclimated to a new way of learning. This makes motivation in PBL a complex issue. The results for medical students are consistent—they enjoy PBL and feel confident about their learning [89][90].

One barrier to using PBL in more diverse settings is the lack of a sufficient number of skilled facilitators in many settings. Classrooms have more students than one person can easily facilitate, and learning to facilitate well is a challenge [88].

A very relevant discussion on the suitability of problem-based learning for engineering has been published by Perrenet, Bouhuijs & Smits [49]. They conclude that "PBL has certain limitations, which make it less suitable as an overall strategy for engineering education". One of these is the constructivist philosophy behind PBL. Engineers must be able to apply concepts that they learn during their education at university to problems outside of the experience they had in the course, since problems they encounter in practice will usually differ from those they have encountered previously in practice and almost certainly differ from those they encountered at university.

It is also mentioned that PBL might not be a sufficient approach to a whole education program in engineering, since the nature of engineering knowledge is quite hierarchical and a failure to understand or overlook some of the concepts may have been impossible to correct during studying only through PBL methodology. [42]

Several different PBL models have been proposed over the years, recently by Savin-Baden, who posits five models of PBL including Model II, which is “focused on a real-life situation that requires an effective practical resolution” [79]. Model II may come closest to describing the nature of ME310. Savin-Baden has found that this type of model arises from curricula with strong ties to industry and tends to emphasise process skills, such as teamwork and communication, over content skills. The other models typically present sample problem scenarios to students, not necessarily from the real world.

In conclusion, PBL is a pedagogical technique that situates learning in complex problem-solving contexts. It provides students with opportunities to consider how the facts they acquire relate to a specific problem at hand. It obliges them to ask what they need to know. PBL offers the potential to help students become reflective and flexible thinkers who can use knowledge to take action. Although the roots of PBL go back to Kilpatrick (1918)[91] and Dewey (1938)[92], PBL has the advantage of suggesting a method to promote active and reflective learning for doing, what the real work is traditionally about [93]. Still, careful research is needed to understand if and how these potentials might be realised in different contexts.

2.3 Multidisciplinary, Interdisciplinary, and Trans-disciplinary Teamwork

Modern interdisciplinary design demands that engineers learn to work well in teams that encompass different kind of learnable collaboration skills. [44]

Multiple disciplinary approaches are becoming more and more popular in different universities [94]. Still, there is confusion on what is meant by different multiple discipline approaches. There is abundance of different definitions for disciplines ranging from: multi–, pluri–, cross–, trans–, and interdisciplinary, to mention a few [94,95,96]. In this study, the focus is on multi–, inter–, and transdisciplinary approaches as defined in the next chapter. These terms should not be used interchangeably.

By definition, in multidisciplinary teams the team members work in parallel or in different time sequences and stay on their disciplinary “silos” or disciplinary base during their work [94,97,98]. Multidisciplinary teams benefit from different disciplinary knowledge but do not create new or holistic knowledge. In interdisciplinary teamwork participants work jointly. The teams’ objective is to find a coherent and holistic end result by analysing, synthesising and harmonising different disciplines. In the transdisciplinary approach, traditional disciplinary boundaries are made transparent and team members share a conceptual framework and aim to address the problem setting by using different disciplinary-specific approaches, theories and concepts [94,97,98,99].

The main objectives of using a multiple disciplines approach in the engineering education context are to provide different perspectives on problems and comprehensive research questions, to develop communication and teamwork abilities, and to be able to solve real-life complex problems in a real-world setting. The reasoning is that this will enhance the graduating engineers’ readiness to meet the requirements of working-life. In this context multiple disciplines can include approaches and levels such as multidisciplinary, interdisciplinary and transdisciplinary [94,97].

2.4 Learning Outcomes: Education Taxonomies of SOLO and Bloom

In order to be able to set intended learning outcomes (ILOs) for a course as complex as ME310, deeper methods of defining those are required such as SOLO and Bloom taxonomies, which are presented here and applied in section “Discussion”. The Structure of the Observed Learning Outcome (SOLO) taxonomy and Bloom’s taxonomy are guidelines for defining intended learning outcomes, and learning assessment. Table 1 lists verbs that students have to enact to work towards ILOs and shows the structure of the taxonomies with different levels of complexity and understanding in learning. The SOLO taxonomy and the 2001 revision of Bloom’s taxonomy are complementary to one another with a few exceptions.

Table 1 Presents some of the verbs listed by complementary SOLO and BLOOM's taxonomies (attained from Biggs, et al [102] and Raduma, W., 2012 [105])

Some verbs for ILOs from the SOLO taxonomy		**Some ILO verbs from Bloom's revised taxonomy**	
Unistructural	Memorize, identify, recognize, count, define, draw, find, label, match, name, quote, recall, recite, order, tell, write, imitate	Remembering	Define, describe, draw, find, identify, label, list, match, name, quote, recall, recite, tell, write
Multistructural	Classify, describe, list, report, discuss, illustrate, select, narrate, compute, sequence, outline, separate	Understanding	Classify, compare, exemplify, conclude, demonstrate, discuss, explain, identify, illustrate, interpret, paraphrase, predict, report
Relational	Apply, integrate, analyse, explain, predict, conclude, summarize (précis), review, argue, transfer, make a plan, characterize, compare, contrast, differentiate, organize, debate, make a case, construct, review and rewrite, examine, translate, paraphrase, solve a problem	Applying	Apply, change, choose, compute, dramatize, implement, interview, prepare, produce, role play, select, show, transfer, use
		Analysing	Analyse, characterize, classify, compare, contrast, debate, deconstruct, deduce, differentiate, discriminate, distinguish, examine, organize, outline, relate, research, separate, structure
Extended abstract	Theorize, hypothesize, generalize, reflect, generate, create, compose, invent, originate, prove from first principles, make an original case, solve from first principles	Evaluating	Appraise, argue, assess, choose, conclude, critique, decide, evaluate, judge, justify, predict, prioritize, prove, rank, rate, select, monitor
		Creating	Construct, design, develop, generate, hypothesise, invent, plan, produce, compose, create, make, perform, plan, produce

The typical student is driven by assessment. They generally optimise their performance for getting the best possible assessment results, rather than best possible attainment of ILOs. Instead, assessment should be implemented so that better attainment of ILOs results in better assessment results; i.e. the focus of assessment should be placed on learning outcomes and how to help students achieve them. Aligning assessment and ILOs in such a way is known as constructively alignment. In order to design and write course ILOs one should consider [102]:

1. Decide what kind of knowledge is to be involved.
2. Select the topics to teach. But beware: 'The greatest enemy of understanding is coverage.'
3. Decide the purpose for teaching the topic, and hence the level of understanding or performance desirable for students to achieve. We need to prioritise, by requiring that important topics are understood at a higher level than less important topics. [102]

These principles are applied later in this thesis in order to develop detailed intended learning outcomes for the ME310 course.

2.5 Towards Sustainability in Engineering Education

Since on the ME310 course students work together with people from five different continents, they have plenty of opportunities to meet and practise different working styles. It is also a eye-opening experience how the ethics of foreign students differs from local ones. Ethical side of engineering education is not getting too much of attention on a course level. Already in 1977, in the Tbilisi Declaration (The world's first intergovernmental conference on environmental education), there were recommendations made that education should increasingly be taken in the direction of interdisciplinary and life-long learning in order to guarantee a more sustainable future. [103]

Assadourian addresses the question, in the State of the World 2010 report, of how to build a sustainable civilisation and what will be the role of higher education in that new world. Should we take the focus to be farther time horizon and what would it require? The report suggests that it requires changes in the curriculum, how the different schools teach and what the roles are of schools in general. Is there a way to ensure sustainability in our teaching? What are the situations and places where the students should learn their professional ethics and understand that many culture differs from one's own on the ethical side too? [103] The report explains some means that are in line with my findings in the results section.

3 Materials and Methods

In this chapter materials and the methods of this research are explained and the reader is walked through the process of implementing of the research design. Materials for this study consist of the details and the context of Mechanical Engineering 310 (ME310) course specifically in Finland since every country organises the course slightly different way. The course structure of ME310 and pedagogics behind it is reviewed. The description is based on the interviews of teaching team, if something else is not mentioned. The location of the course, Aalto Design Factory, is seen as a factor that has an influence on the course results and that is why it is depicted. Some focus is also given to the teaching methods and organisation of the course faculty. These materials are used for mapping out the background for the second research question of what are the best practices of the course. The method explained and used for the first research question is semi-structured thematic interview. This is followed by analysis and limitations of the methods used.

3.1 Materials – ME310 course

ME310 is an interdisciplinary, project-based course for master's level students in Aalto University, and represents a true integration of engineering, business and design disciplines. Originally created at Stanford University, the course has operated continuously for over forty years. During the course, for over nine intensive months, students learn and apply the Stanford/IDEO design process in product development to prototype, test and iterate in order to solve real world design challenges for multinational corporate sponsors. Example industry partners are Audi, Autodesk, BMW, Nokia, Panasonic, and Xerox Corporation. Each team also receives a sufficient project budget and dedicated lab space (commonly known as the "310 loft"). Originally created to provide engineering students with real life engineering challenges, the course has shifted from practical engineering experience, to design of mechatronic systems, to design innovation, global collaboration and entrepreneurship. All student teams complete the engineering design process from defining design requirements to constructing functional prototypes that are ready for consumer testing and technical evaluation. Plus, a high premium is placed on community building and networking amongst ME310 students, alumni and faculty. The student team is paired others from different countries. [101] This set of diverse universities in various countries forms a network, which is called the SUGAR network. Each member of the network has their own teaching team, ways to operate and environment where the course takes place.

3.1.1 Brief History of the ME310 Course Development

Carleton and Leifer provide a sneak peek into history of ME310 through their paper. The most noteworthy development phases are explained in this longitudinal study. The course was started in 1967 in order for students to learn practically designing machines. In 1970, a new aspect was introduced; interdisciplinarity and combining analytical skills with creativity. During 1972-74, seeds of prototyping and iterating were sown. From 1975 to 1981 the focus was on emphasising real-world problems. In 1981–1990, electronics, mechanics and programing became more relevant to the industry projects. After engineering focus, the emergence of Design Thinking and recognising the value of hands-on guidance and mentoring on the student teams was purported. Between 1990 and 1995, rapid prototyping was given increasing emphasis. For example, a paper describes that era thus: “Student assignments in the first quarter taught them about the journey of product realisation, starting with raw product concepts. Students were pushed to iterate and rework all mock-ups and prototypes, and they were encouraged to fail early and to fail often to improve their thinking. One of Leifer’s fundamental design axioms became “All design is re-design.” He gradually added, “All learning is re-learning. All coaching is re-coaching.”” Around 1995 – 1998, Design was recognised as a social process and a multidisciplinary approach with experienced students on relevant fields forming each team was adopted. Furthermore, rehearsal exercises and SUDS (Slightly Unorganized Design Sessions, where teams enjoy food, drinks and some light programs designed by each team in their turn for the other teams and faculty) were introduced in order that students understand how other disciplines work and create sense of community. Between 1998 and 2004, entrepreneurship was emphasised and the language and approach was for shifting teams to act more like a start-up working for a client in a “business environment”. Understanding the benefit of not closing the design space too early and new prototyping challenges called Critical Function Prototypes (CFP) and Dark Horse Prototypes helped students to expand their team’s creativity, limits and thinking. Importance of learning from other teams, as well as within the teams in the class, and helping each other was promoted. The sense of community was emphasised and according to the students’ reflections it had a major role in the success of the course. From 2004 to 2009, engineering design was truly multidisciplinary, multicultural, and even multi-purpose. The student teams were paired with teams from global universities, which offered an opportunity to learn global communication at best and at worst as a lesson for their careers and lives. The paper states about the development: “Unlike all previous eras, the students surveyed from this era ranked traditional “soft” process skills – such as project coordination, team management, presentation skills, and start-up mentality – as having lasting value, compared to discipline-specific content skills. From 2009, onwards the course briefs started to develop more to foresight direction and might provide another shift in pedagogy and industry partner interests. [7]

3.1.2 ME310 in Aalto University

ME310 has been taught in Finland eight times during the last ten years and altogether 99 students have taken the course in Finland. It has got its own place in the curriculum and a strong brand identity as a very intensive but a rewarding course. Interest towards the course has been solid and thus students are chosen by interviews. The course takes place in Aalto Design Factory, which emphasises prototyping and tries to follow the principle of being able to execute one's idea in seven seconds [15]. The course has its own teaching team that instructs around six teams every year, but the number of the teams might vary yearly. This section also explains course milestones and teaching methods as facilitators of learning.

The ME310 Course lies in the curriculum of the Aalto University School of Engineering, department of Engineering Design and Production as a special module of Product Development. Even though mechanical engineering department has the course's organising responsibility, due to the interdisciplinary nature of Aalto University, it is possible to complete this module through all the master's programs in the University. According to the study guide [8], the purpose of the module is to complement the professional skills acquired in technology and other fields of studies with learning product development processes and methods through projects. No previous experience of product development is required. The study guide continues to explain how prior knowledge and personal performance will be tested during the course. The challenges will be the methods and team projects that will require mental skills emphasising self-reliance, responsibility, activity and social skills while flexibility and ability to handle mental stress are indispensable. The difference to the past university courses is that the ambiguous problems confronted are ill defined, but they correspond more to the real world challenges.

The Aalto and Stanford versions of the course are very similar, such as the team sizes of three to four people, but of course there are some differences too. The most remarkable difference that was found is probably that the Stanford course participants are mainly engineers while Aalto students by definition come from business, design and engineering backgrounds. This creates more challenges, but also more opportunities. Course demographics can be seen as a major factor influencing in the acquired working life skills. In the Stanford curriculum, the course is mandatory for Stanford master's students specialising in Engineering Design, and an elective for students from other disciplines. In Aalto University the course is the most intensive product development course on the curriculum and it is entirely optional for everybody. Students are selected through an application process that is explained in the next section. [9]

3.1.3 Application Process

Each year the number of students is determined based on the number of the projects sold to industry partners. This has been typically from four to six project teams during the recent years. Consequently, around sixteen to twenty-four students a year are able to take the course. The trend lately has been that there have been around hundred applicants per year and thus competition makes it quite difficult to be accepted onto the course. There is a pre-selection of the applicants by CV, letter of motivation and portfolio.

First, the pool of prospective students is ranked solely by their credits completed. Next, the best students, ranked by their references, are invited to the interview. Around double the amount of students for the number of the places on the course are interviewed. In the interview, there are always several members of the teaching team and some alumni present to do the evaluation. After all the interviews there is a synthesis and selection decision made, ensuring the desired balance of engineering, business and design students for each group.

The purpose of the interview is to examine the personality and skill set of the applicants while trying to spot weak links in terms of motivation. Also, if the corporate projects are known prior the selection dates, the special skills valued in the different projects may have a role in the selection. It is very important to invest the time in the interview process. It works as a two-way benefit, since instructors will know which applicants they want to work with very closely and also applicants will know if they want to invest nine months of their life in the course.

The selection process must have some influence on the end results of the course, but it is out of the scope of this research to trace the impact of handpicked students in relation to course pedagogics consistently producing extremely good results. [16] It is a part of the course setup to emphasise in the interviews how hard it is to join the course and how proud one should be about if accepted. Here, the ME310 experience and journey of professional treatment with appreciation is begun. [11]

3.1.4 Design Process

The ME310 course presents design thinking to the students as an approach of solving complex product development problems. In the Figure 2, the reader can have a simplified overview of the ME310 design process. It is a cycle-like process, which starts from defining the problem. Defining starts from a design brief that outlines roughly the problem and the context. The process continues with familiarizing oneself to the area of problem and brainstorming solutions, or parts of it, that might take the project further with different brainstorming techniques. Brainstorming leads to ask relevant questions and build prototypes based on them. Prototypes will be tested with users, the questions are answered through testing and at the same time more are discovered. After one cycle, the process continues from the beginning and is continued until satisfactory solution in relation to available resources is achieved.

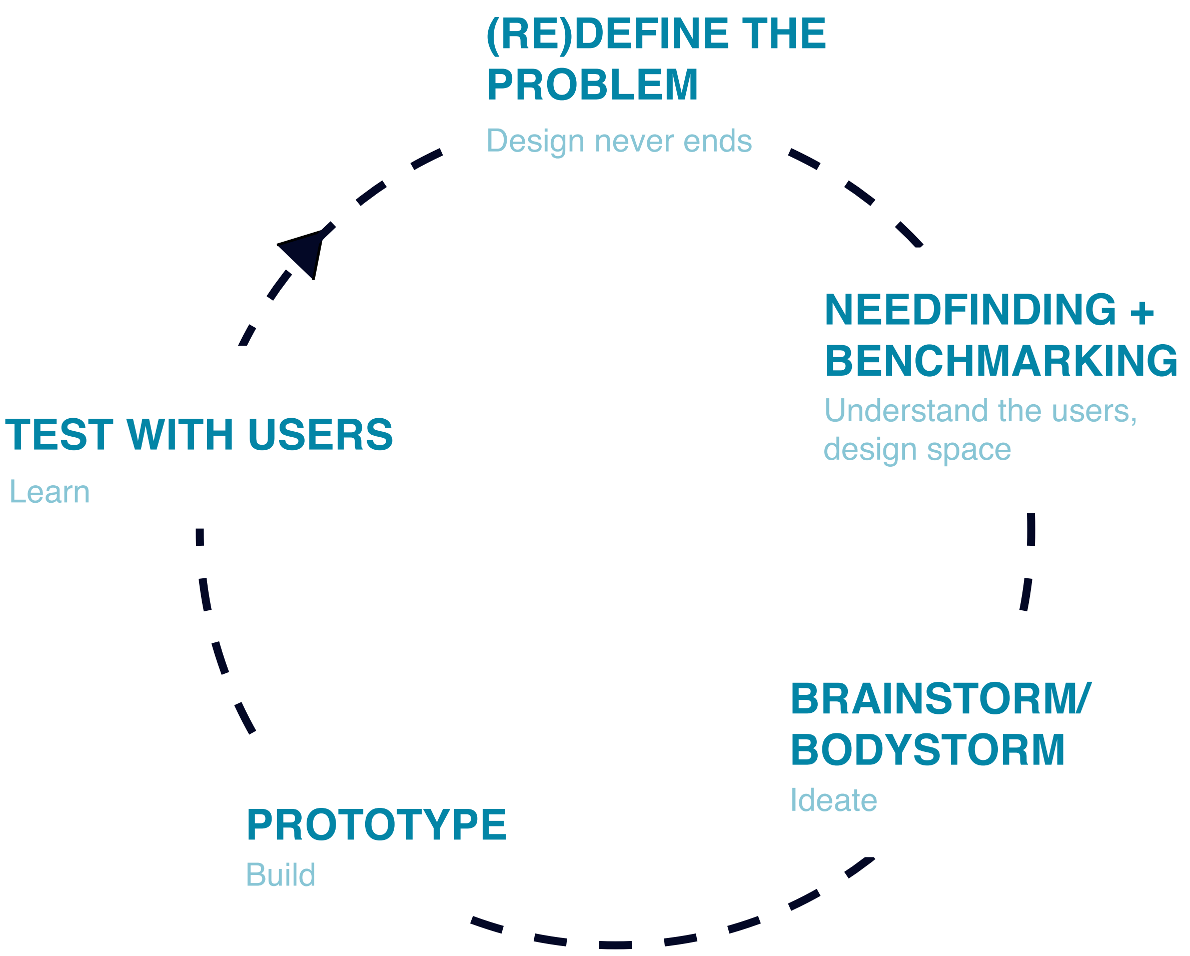

Figure 2 ME310 design process (source: teaching material of ME310 course 2012)

3.1.5 Milestones and Deliverables

The question answered in this section is that of how the course is controlled and the similar learning experience ensured for all students when the projects are different each year. This section is quite detailed because of assumption that some of the best practices should be found from this section.

The course is divided into three different periods with different themes and slogans: “Fall period – make it up”, “Winter period – make it real” and “Spring period – make it happen”. Furthermore, the course is sub-divided into two to four week periods entailing different milestones relevant for the project. Figure 3 illustrates how the fall quarter milestones are presented to the students. In the rest of this chapter, the researcher will thoroughly explain how the course is structured and the underlying motives for each section, as interpreted by the teaching team. Generally, the motivation for each milestone is always the best possible learning experience for students. The experience is carefully manipulated during the nine-month period starting from very little steps of introducing constructive language, ways of working and philosophy.

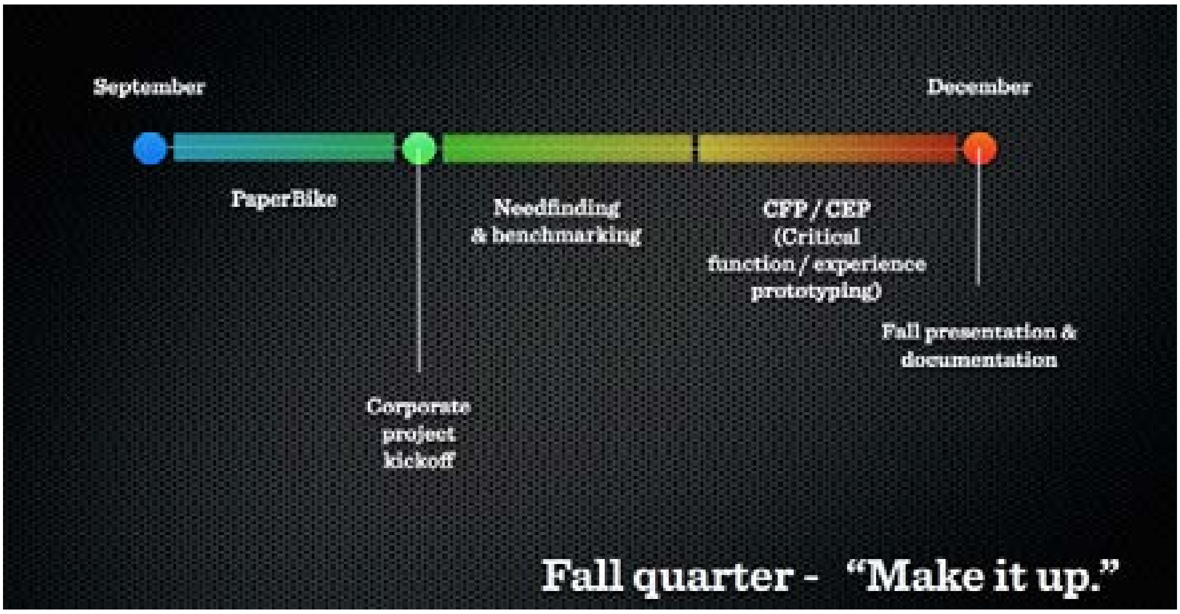

Figure 3 Fall quarter milestones. (source: teaching material of ME310 course 2012)

According to Tuomas Sahramaa, the core member of teaching team ME310 2012–, 2013, everything in ME310 starts with small steps. In order to get something done the nine-month course, it is necessary to break the subject down into smaller pieces. The most important goal, he sees, is teaching the design process little by little and building confidence. The tools the teaching team has been using for students are, for example, giving examples from previous successful years, introducing the whole design cycle in small parts and then acting like a moderator to their advancing process with appropriate pace. It is also really important to determine whether the project is progressing in the way wanted. This is controlled by weekly small group meetings (SGMs) where the teaching team finds ways to deliver interventions or re-energise groups that are groups feeling discouraged, which is common during the projects. As an intervention, they ask prompting questions, suggest, motivate and try to bring in fresh angle to the problems at hand. The teaching team also consists of different personalities, and the team pick, based on the observations what kind of need and guidance there is needed in the process, who is the best person to intervene. The ultimate goal is that the students understand the innovation space, the problem and are introduced to and trust the design thinking process before making any very resource-intensive decisions. In the next chapter the ME310 design process and its most important milestones and their pedagogical meanings are described. [11]

GETTING STARTED

After the selection, the students get to know each other at the lectures and are put into action right away in order to communicate the pace and tangibility of the course starting from the very beginning. There are some exercises to break the ice and to introduce part of the design philosophy of the course. The first icebreaker, is already at the first lecture that lasts around twenty minutes and consists of designing and building something. Then students get their first glimpse of the meaning, numbers and the resolution of the prototypes that are made during the forthcoming nine months. The second challenge takes three hours and encourages the students to express themselves physically and also to build something concrete. It is also seen as really important that a family-like atmosphere is created by getting to know each other in the class and by treating everyone in an equal manner. This goal is tackled formally with Pecha Kucha (ten only-picture slides, twenty seconds each) [12] presentations by everyone, including teaching team or anyone present, and then informally during every Thursday having a meal and spending time together in event called Slightly Unorganised Design Sessions (SUDS). In these sessions a student group or the teaching team, included in the rota, in turn plan and organise a program outside the normal curriculum. This encourages students and staff as well to get to know each other better than by their professional roles, and will help them during the year to trust each other's and deal with any possible team dynamics issues. It builds confidence in the groups and establishes family-like atmosphere, which is a key component during such an intensive project. Building personal and professional bonds will pay its dividends during hardships in the long run. [11] [15]

REHEARSE PROJECTS

Then the rehearse projects before the corporate project starts, where the design process is executed first partly and then fully. The first rehearse project lasts three days and is again some kind of competition, in which assigned groups build together something together. In 2013, for example, it was a projectile launcher of balls with budget of 10 euros where accuracy and power were graded (some scrap material was provided by the faculty).

PAPERBIKE

The second rehearse project is the global paperbike competition, in which every group of students build a paperbike for a competition, in which the rules are changed every year. It could be a game of some kind, like dodge ball, and only paper materials are accepted. Only one hundred grams of the bike can be made of materials other than paper. Here, the pedagogical aspect is that the cycle of design process is expanded and opened up more at every new cycle, building up confidence though some students might be outside of their comfort zones. The students will experience how it feels to execute something from an idea to a product, while the teaching team tries to generate an atmosphere where there is no fear to build products with other people. In addition, agreeing what to build is practiced since it might not be familiar to all the students. Paperbike is a perfect subject for such goals, since it is quite certain that anyone has never built a paperbike before, so no one can claim to be a professional or an expert on the topic. By putting everyone on the same line, it promotes equality from the design process point of view and everyone should feel that they could contribute. Students will learn new basic skills, such as using a power saw, and develop less fear towards actual building. It is a good chance also for the teaching team to observe the behaviour of the students in action and spot possible team dynamics issues before jumping at the corporate projects. It is an intense time, so it tests out quite well the chemistry of intended project teams and brings out the real personalities of the individuals while people stop being polite as things get real. For a nine-month project, it is really helpful to see this three weeks teaming prototype. As a summary, the project is fun while the building together is in great role. In addition, on the administrative side, it is not too costly.

STANFORD TRIP

The paperbike competition culminates in a two-week trip to Stanford University, California. The bikes are transported with the normal weight and size limits of suitcases as an extra luggage for the students. This makes it exciting and adds its own challenges for the design. The final battle with all the participating countries (SUGAR network http://www.sugar-network.org/), and teams is held in the university area. The two weeks in California are also full of teaching and getting all the teams aligned, not to mention teams are paired with international counterparts as they receive the corporate projects as a group. At this point in the trip there might be slight changes on the teams from the paperbike teams, and that emotional effect should not be underestimated but appreciated accordingly. Teaching team should consider that teams might perform better as a corporate project team if they have all the created emotional connections remaining during the paperbike building and travelling, so splitting of the paperbike-teams should have a substantial advantage. Some expectations management should be used towards splitting the teams, and an open opportunity given for the students to talk to the teaching team off the record might be useful. After the paperbike project, there is an organised chance for the first one-on-one sessions for students to talk to the teaching team confidentially about who you are able or unable to work with. This is also a tool for making the instructor–student relationship a bit more personal while still maintaining authority. The second week of the trip is really crucial in order to get teams together and found a base for the future collaboration. The week consists of exercises done within global teams and starting the initial ideating and prototyping for the corporate project after getting the design brief of each project.

DESIGN BRIEF

The corporate project starts with a design brief developed together with the corporate liaison and teaching team. A good design brief is balanced in terms of openness and a well-defined area of interest. It should enable students to browse endless opportunities, but still be narrow enough to give the company insights on the area that they are interested in. The brief takes place is after the rehearse projects have ended, so that the process would be more or less familiar to the students and they would be able to trust the process without rushing in pursuing solutions without any evidence yet. Sometimes the first ideas stick in their minds, and it might be difficult to open one's mind again for other possible solutions. [11][15][16]

NEEDFINDING AND BENCHMARKING

After the trip to California, the teams start with their needfinding and benchmarking mission. The goal is to go wide and deep in the information of problem in the design brief and the context at hand. It is about building up expertise about the subject, but also teaching students to appreciate the needfinding process. In ME310, at the beginning of every project one should start with fresh eyes benchmarking existing solutions to understand the importance of that initial step. Tool-wise, students are taught to make all the benchmarks visual, working with pictures, cluster findings and possibly quickly prototype already some solutions initially. The documentation will need illustrations so it is emphasised to take photographs of everything that the teams do and see. Here, the students will learn practically how to create dialogue around some benchmarks and findings, and look at the solutions space and be able to constructively validate or invalidate the existing solutions in the project context. Students will first go out and try to find needs and benchmarks, and if that is not adequate, the teaching team will give some constructive advice. For a teaching team, the hardship is to avoid making the decisions for the team, since ultimate decision-making should always be left to the students: that is the way they learn. The course's key do-test-learn cycle is already seen here.

CRITICAL FUNCTION PROTOTYPE

The idea behind the Critical Function Prototype is to practise breaking down a big problem into small enough pieces to chew and be able to recognise what is critical for a larger system. It also functions as a time saving mechanism since CFP is defined on the course as the most important part – should it fail, it will cause the whole system to fail. Without that 10 % of the project, the other 90% will not work. Building CFP practises the whole process to identify the most important functions and parts and to reach early consensus in the group. This is valuable learning in itself and will be practical in the later phases of the project. It is said that engineers might think naturally about products as a compilation of components, but both system and component level thinking is needed during the course. CFP also acts as a tool for everyone to understand how the prototype or idea works, since designers or business students might not be familiar with that "breaking things down to components" mindset.

CRITICAL EXPERIENCE PROTOTYPE

Critical experience prototype is similar to CFP, but it focuses on the user experience. It might not be a function, but about what the most important emotions and experiences are that the user will feel while using the product. User experience will be isolated and systematically tested with users in order to validate and refine the experience.

FALL PRESENTATIONS

After all the needfinding, benchmarking and building it is time to make the project explicit and interesting. Presentation is an excellent tool to show what is done during the fall in a concise format. In ME310, it is formulated as a pitch-like presentation, in which the key motivation is to force it to be made understandable for outsiders. The time limit is only ten minutes, so it does not leave time for blabbering. Start-up pitch coaches are used for coaching the best out of the teams. The attitude that the students are taught is confidence that the need they are pursuing is the most compelling, and the team is going to solve it in the best possible way. The goal for the presentations is to be informative, memorable and entertaining. Breaking the idea into simpler and smaller terms also might open up a new path for the project. Taking something very technical and mechanical and explaining it to a normal person is a skill that ME310 wants students to develop. It is hoped that the presenters will throw themselves to the stage as showmen or rock stars, while their presentations are made to look nice and interesting. Some might not have much experience in presenting, so it is a great opportunity just to practise before a wide audience. There are three presentations altogether during the course, so it will be valuable skill for the last presentation.

DOCUMENTATION

After the presentation, there is roughly a week to finish the documentation of the semester. Normally, it takes the form of some hundred pages of written text and pictures including an executive summary, vision, context of the problem, introduction of the team, documented design development with needs and users and the design specifications for the realised prototypes. Some writing requirements are set, for example the documentation should articulate the need well, document the process of the team and the solution in a consumer friendly way. It should be in a narrative format, in chronological order, expressing measurements, dimensions and all the complete blueprints of the prototypes. The documentation acts like a tool to organise the thoughts and ideas, and elaborate on the presentation. It is good practise of the skill of breaking down the project and formulating all the research in a readable format. It forces students to tell a story and understand their own project better. Personal reflections are also included in this documentation where, there is a chance for everyone to speak their mind out about the project and their feelings. After the documentation there is a Christmas break and the course continues with Winter quarter illustrated in Figure 4.

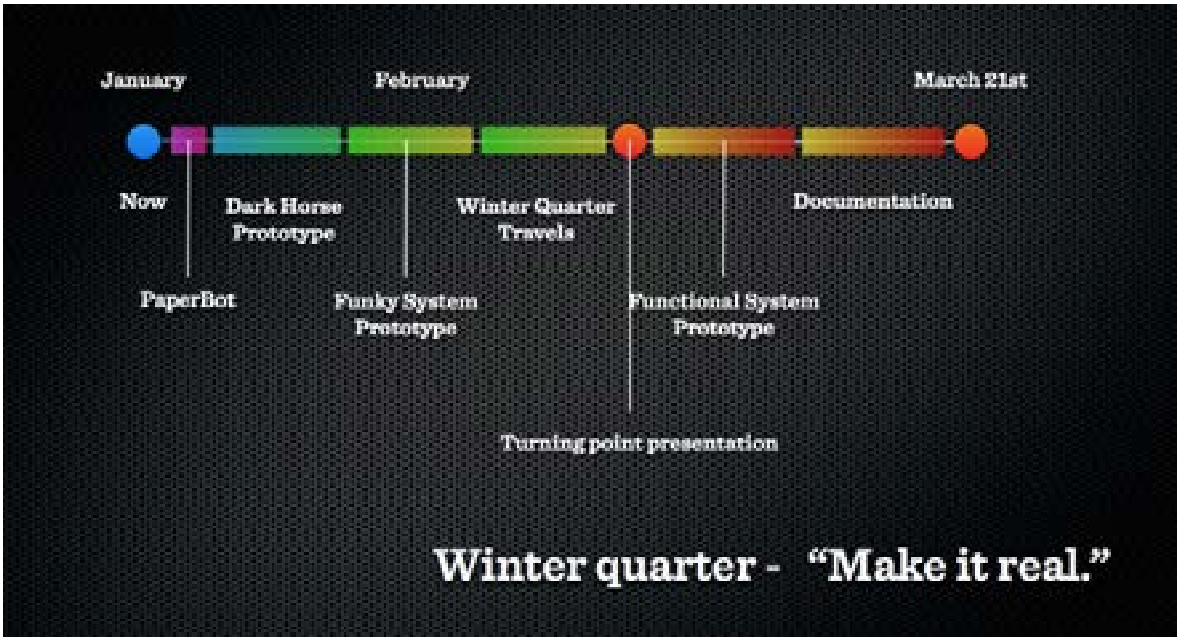

Figure 4 Winter quarter milestones. (source: teaching material of ME310 course 2012)

PAPERBOT

The paperbot challenge was introduced for the first time during the Winter quarter of 2010. Because the present projects are increasingly pursuing solutions that require mechatronic skills, the teaching team decided to make people confident with electronics with this small, week-long, funny exercise. The themes vary each year, but for example in 2012–2013 the task was to create a robot out of paper, a microcontroller, sensors and actuators that would work independently and be able to express four different emotions. It is normal that there is team members who have not have any experience with electronics nor coding. For those members this is the exercise where they can learn the basic language to communicate by using it and understanding how much time and effort it takes to manufacture something that may seem quite simple on paper. On the faculty side, there is some extra support provided by electronics and mechatronics experts. The focus is on teaching with a learn-by-doing method and students will make everything by themselves and at the end present the results to a group of invited students and staff. This can be seen as a witty compensation to the constantly changing demands of the corporate projects.

DARK HORSE

The winter quarter starts properly after the paperbot exercise. The projects have been put aside for a while and it is time for expanding the last stretch to the solution space. Figure 5 shows how the divergence is built during the start of the project and after the Dark Horse, the projects will be converged towards the final proof-of-concept prototype. Dark horse is famous for its ability to allow students to expand their thinking-outside-of-the-box to try something different. As dark horse is defined as “an entrant in a contest that is judged unlikely to succeed”, it describes well its function as a liberator of thinking in the ME310 program. It is one of those ideas that was too crazy to start with and never ended up going to the final drawing board, but now the students prototype it and see if there was something valuable in that thought. It is said that almost every team includes something from their Dark Horse prototype in the final prototype. The motivation lies in breaking the formed habits so far, possibly finding new paths to the project and inspiring new thinking before making decisions that should not be made before it is absolutely necessary. It is also a reminder not to stop experimenting at any phase of a project and leave opportunities open.

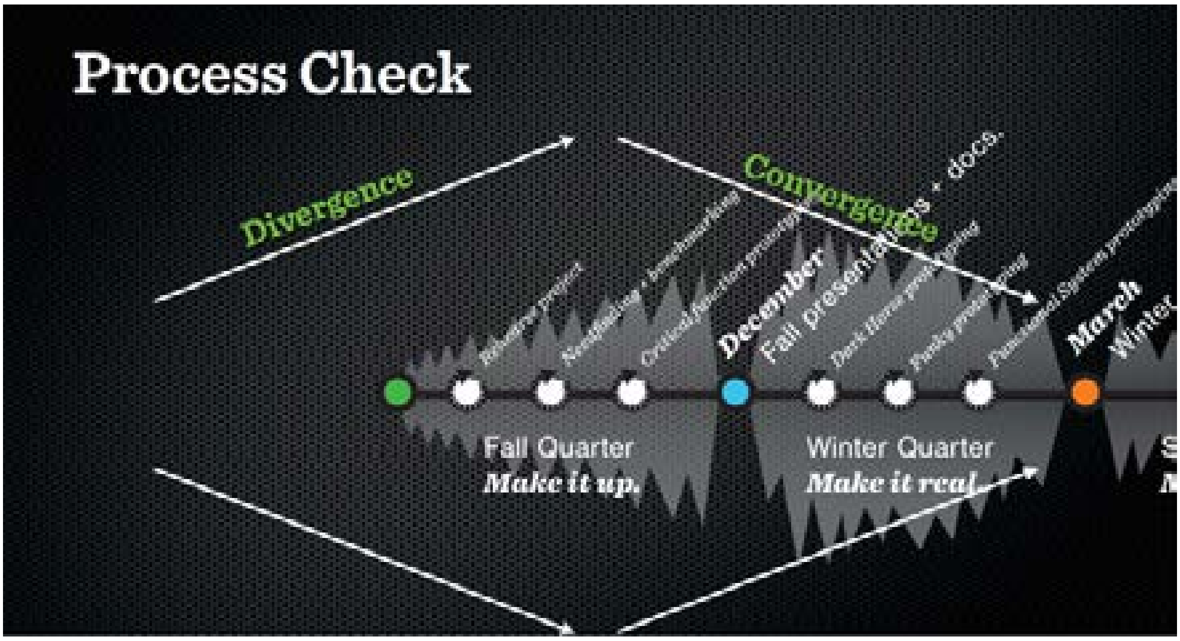

Figure 5 Divergence – Convergence of the solution space in relation to the time. (source: teaching material of ME310 course 2012)

FUNKY PROTOTYPE

Funky prototype is a rough prototype where the whole thing is imagined the first time and begins to come together. It acts as a tool to create a shared vision for everyone in a team, while the focus is more on getting parts fit together in the first place rather than on the finishing of the prototype. Every design needs small incremental decisions and some of those are made during the funky prototype. Time for building and testing the prototype is given around two weeks.

FUNCTIONAL SYSTEM PROTOTYPE

After the funky prototype, the focus of the project is turned more towards the final prototype and system level thinking is emphasised. The next prototype is more refined with working sub-systems. It also acts as a start of forward planning and it teaches students that it takes a surprisingly long time to decide which materials you need, get them shipped, and all the other phases in the process of manufacturing. Hopefully, students will get inspired thinking ahead since the majority of the prototypes that blow a deadline, fail because of not understanding the production schedules. Just to outsource one part from an external company takes time for meetings to be scheduled, the first version or sample to be picked up, and allow for corrections should there be something wrong with that sample. It is very useful to understand that process already at this point of the project. It is also time to realise how much parts cost, where they can be bought and what one really needs. The functional system prototype's value is in making that material schedule early enough, thinking about the components of the design, understanding how much time everything takes in order to have it on the level of refinement planned and how complex a process it is. Turning point presentation, winter

TURNING POINT PRESENTATIONS

Again, in order to present something together, students need to make up and agree a vision on an international level. This results in new challenges in the decision-making and the teaching team should properly prepare for supporting students. Compared to fall presentations, where there is significantly less flesh on the bones of the project, Winter presentations should state a clear vision towards what the team is after for the final gala. It needs to be a good enough vision and the presentation should convince that you are able to realise the vision and that the product itself is innovative and ambitious enough. There is a lot to do with how the story is told, how convincing it is and how desirable the product is, but that is what the teaching team expects to be delivered.

WINTER DOCUMENTATION AND DESIGN REQUIREMENTS

The rationale behind design requirement is to find something as a requirement that you can measure and through that, students practise seeing their prototype system as a set of functions: breaking their prototype down to steps that are measurable, developing sense of hierarchy and, more importantly, making decisions about what to include in the requirement list and what to leave out. After winter documentation the last quarter of the course starts – Spring quarter. Milestones of the quarter are depicted in the Figure 6.

Figure 6 Spring quarter milestones. (source: teaching material of ME310 course 2012)

X IS FINISHED + MANUFACTURING PLAN

X is finished represents a deadline where one part of the final prototype for the gala should be finished. This is also the time to plan all the acquired materials needed and which manufacturers will do the final production of the parts.

PENULTIMATE HARDWARE REVIEW

Penultimate acts as a soft launch and is a gate where you can fail or succeed. It is a forced deadline, in which the minimum requirements for the EXPE should be met in terms of a presented prototype. Soft launch shows if there is going to be a crisis before the actual show. Presumably, without this deadline there will not be a fail-safe mechanism to see what the critical parts of the overall presence of EXPE are missing and what has made good progress. Extra rationale for taking this step is to prevent the on-going expansion or addition of new features in a prototype and be realistic about what can be achieved before EXPE.

EXPE DESIGN FAIR IN STANFORD

Students present their product in fair with a booth and in presentations for international crowd and potential investors. It is the main event of the year in d.school and hundreds of visitors come and see it. The requirement for the students is to present their prototype in the given area inside the d.school in the way they see as relevant to their project. Coaching is given before the fair in order to give ideas and tips for making the booth experience catchy and comprehensive.

FINAL DOCUMENTATION

After EXPE there is a week to expand all the material produced after Winter documentation and put it in one book with a finished, elegant layout. The documentation is the only thing that is lasting out of the projects and it acts as an assessment tool as well where the students should record all their hard work in a concise format containing the design of the prototype, process of making it and a reflection of the learning along the way.

3.1.6 Location of ME310: Aalto University Design Factory

In the year 2010, a new university was formed, unprecedented in scale and economical significance for Finland, that should answer to the desperate call of new innovations that would bring the former success of the country back. It was a merger of three top universities in Finland in the fields of arts and design, economics and technology, which brought together Helsinki University of Technology (HUT), Helsinki School of Economics (HSE), and the University of Art and Design Helsinki (UIAH).

The new university's working name was "innovation university" and later, after the name contest, established as Aalto University. The purpose of the university was to create new possibilities in multidisciplinary education and research. [13]

Aalto University's spearhead project Aalto Design Factory (ADF) is described in many ways, since there are a lot of activities happening. As an experimental platform of education, research and application of product design its purpose is to educate the best designers in the world. [14] The President of Aalto University Tuula Teeri comments on about the future of work in the Annual Report of Aalto Design Factory [14]:

> *"Nowadays, our education doesn't only prepare students for specific fields of work – rather education is becoming more generic and universal and we should actively think what are the skills that innovative professionals need in the future. Seems like the students at Aalto Design Factory are learning exactly those skills that are needed and this is something I want to incorporate to the whole university. Our students already hold the talent before they have set their foot to university and our task is to support them and make their talents flourish. In order to do this, we first need a new mentality of trusting the students and asking them for feedback."*

According to the study called Aalto University Design Factory in the eyes of its community, the ADF consists of different elements such as community, spaces, ways of doing things, research, and education. Design Factory is a platform that practically hosts product development courses and provides all the necessary support for realising proof-of-concept prototypes and other end results of the courses. The working spaces are often described with emphasis on the supporting factors of physical spaces that allow people to work better, such as tabletops that are made of glass, so that they can be used for documenting or fast sketching. [13]

ME310 as a course uses heavily the resources provided by the ADF. For example, while doing the concept development, there are many spaces to brainstorm, some materials to do prototyping quickly with small resolution and help to co-create ideas. When the ideas are being developed further and more sophisticated prototypes engineered, the facility provides e.g. design support for CAD and manufacturing, metal workshop with lathe, milling and welding machines for heavier metal works, wood shop for woodworks, electro shop for building electronics, paint shop for finishing prototypes, and administrative help for acquiring all the materials required for the prototypes. It is not always clear to outsiders that acquiring needed materials quickly is a problem in universities, and in Finland especially, because of the bureaucracy, long delivery time or lack of storage in the country. It is essential to have staff who understand the need to bend the rules as much as possible without breaking them supporting the design process in order to have results that excel year after year. [11]

The core of the Design Factory is the culture including the attitude that everything is possible, and the excellent quality of given support. Also because the courses are done with industry collaboration, there is scope to have a budget for actually realising the ideas quickly and through that genuinely share the freedom and the responsibility of the results with the students. As ADF is an open platform, it is fairly easy to get access to the facilities on a daily basis. This brings in a lot of interesting people with good ideas, money or skills to spend time in the Design Factory and contribute to the community. Still, the most common reason to come to ADF is participation in one of its courses. While having a vibrant community with entrepreneurs around, it is a great place to do user tests and collect feedback since the idea of prototyping is familiar to everyone and the do-test-learn cycle is integrated in the minds of every member of the community. ADF attract a lot of visitors daily and thus it allows students to practise presenting their projects every day, as there is always a group of visitors asking what is the project is about. [14] This contributes to the learning while making the projects, design briefs and solutions more explicit. The staff also shows some examples and, in accordance with its spirit, the whole building is on the move, changing and experimenting all the time. [16]

ME310 takes place in the whole ADF building, but especially in the Loft. The Loft is a dedicated space where students spend most of their time. They have total control over their own desk and walls. Loft is made to feel like a nest in order to create a safe atmosphere and through that encourage building more and eventually having better results on the course. [15]

3.1.7 Group Spirit Enablers

Part of the course is the carefully supported group spirit among the whole class. Extra effort is taken to make the loft feel like a nest and a home base. The teaching team makes sure that the SUDS are always happening, cheerlead for the students, if necessary, and encourage students to trust the process, sometimes even helping with prototyping in order to keep things going. [11]

Commitment towards the course grows little by little through small, successful and meaningful tasks. In addition, when people start liking each other they start to care about finishing all the assignments. When the project proceeds and students create deeper understanding towards their topic they start constructing the problem space and adjust their own role in it, and begin feeling that they are important. Here also the story of Aalto University being the best in Finland and the fact that the students have been picked from a large pool of applicants contributes its own boost to the self-esteem and will encourage students to live up to their expectations. [17]

3.1.8 Teaching Team and Course Organisation

This section deals with the teaching team, how it is selected, the roles within it, how student teams are supported, and generally sheds light on what happens behind the scenes of the ME310 course and the organisation of the course in Finland.'

The teaching team in Aalto is selected to be multidisciplinary, valuing qualities in teaching skills, organisation and energy. The selection is also based on team dynamics, since it is stated that everyone after the course should be able to act as a member of the teaching team [16]. It is normal that someone from the previous teaching team continues for the next year as well. There are teaching assistants that have worked two or even three classes in a row and through that contributed to the silent knowledge that might disappear otherwise if totally new members are selected. The teaching team consists of four to six teaching assistants and the responsible professor. Exceptionally, on ME310, the teaching assistants take care of the lecturing. They are responsible for all teaching, budgeting the course, travelling and administration. They have a community in ADF to help them on a daily basis and thus extra resources are available almost at any time requested. The teaching team also communicates widely with other countries where the counterparts of the current projects happen. Each team in ME310 pairs with another team from a foreign university, consequently teaching teams also have to collaborate. Every global team has its own faculty, teaching assistants, project coaches, and dedicated space. Some universities have developed their course further during the years and some have just joined the ME310 SUGAR network and get support to start from other partners. The foreign collaboration has been possible for the last ten years. In the latest classes, up to three different teams from different countries have been connected as a global group. [18]

Moreover, a broader network supports the student teams each year. Project coaches are assigned to specific teams, providing relevant expertise, project advice and support. In Finland, coaches are often alumni who have expressed their interest for helping the next class. Teaching assistants have shared the roles to care for different everyday operations while staff of Aalto Design Factory helps to coordinate ME310 logistics. [16]

Figure 7 presents a visual summary of all key relationships occurring in 2009. This study concentrates on the last ten years of the course, but there is a longitudinal study conducted about how the course has developed during its existence by Carleton and Leifer since 1967. [7]

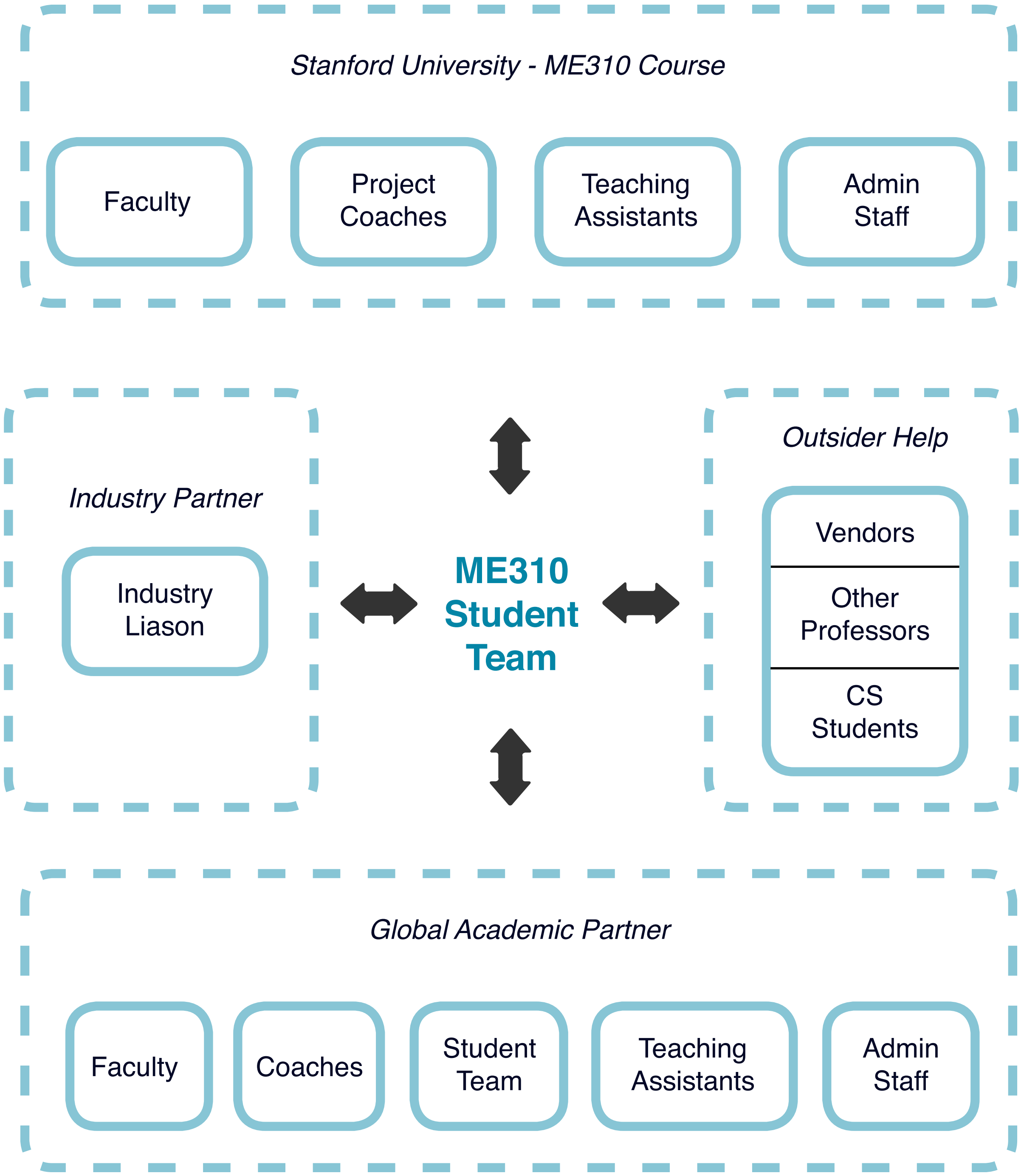

Figure 7 Network view of ME310 in 2009. (Carleton T., Leifer, L)[7]

The teaching team meets the students on Tuesdays and Thursdays. On Tuesdays, there is a lecture or workshop, and on Thursdays, there is a SMG for each student group and an LGM. Before SGMs, the teaching team tries to meet up briefly, goes through the situation of each group, and divides roles according to what kind of intervention is needed.

The task of the professor of the course is to be the dealmaker with the industry partners at the beginning and during the year in order to make sure that the course will continue the next year. This requires networking and salesmanship. Building relationships with corporate sponsors needs active communication and constant pitching to ensure that the constant deal flow exists. The professor will, in addition to bringing in the projects, take part in the big decisions and contribute to deliver the best possible learning experience. He or she gives feedback in SGMs based on the experience. He or she also acts as a stress reliever and unifier when the teaching team is stressed. The professor deliberately stays out of day-to-day business, and thus delegation and trust of the teaching assistants are a key role. The professor also has the higher oversight of things and the ultimate responsibility. He or she is the one who would step in and protect the learning experience of the students if there was a hard client forcefully driving a direction harmful for the learning experience. The professor is the one who makes the larger decisions and gives permission for larger purchases and authorising travel decisions.

3.1.9 Teaching Activities

There are some shared teaching activities in the course globally. They are explained in more detail in this section. The ultimate goal of the ME310 is to change thinking of the students [16]. All activities shall contribute towards that goal.

SGM

SGM stands for small group meeting and is held every Thursday in order to stay in touch with the student teams. SGM is an informal event that lasts up to an hour where the student team takes the lead and shows the learning of the week. The teaching team observes how the team has concentrated their effort and time and whether it is relevant for the design brief. Basically, they give well-timed feedback, ensuring that the teams are going forward all the time sensibly. They might ask probing questions, propose that the team needs to take a step back and brainstorm more, or suggest tackling the brief from a different angle that is more compelling for the users. The teaching team might also choose to dedicate feedback areas among its members, before meeting the students, in order to give broad enough feedback. SMG is also a time to re-energise the group if they need it. They provide tools and suggest user-scenarios that could possibly open new paths. The teaching team also observes if there is a specific topic or area that needs clarification and accordingly gives a lecture or a workshop on it. For example, in 2010 teaching team conducted an experimentation called “Dirty Tuesday” where students who were stuck and not able decide what to build, were given a task for a day. The students had to build according to a totally new design brief that was very close to their original, but something was altered dramatically. To illustrate this with an example, Activision team, whose brief was to redesign a game controller, should design and prototype a controller where the use of hands is not allowed. This was a success where the team got themselves back on track building prototypes and through that got their confidence back. [16]

LGM

The LGM (large group meeting) is for discussing group-wide progress concerns and reflecting recent experiences, for example from the SGM’s, in order to learn. It is a time to inform about important course dates, like in a “weekly company meeting”, and make sure everyone is on the same page. It is also a way to close down the week, where the work stops and students can reset their brains. Normally, LGMs are held on Thursdays after the last SGM.

LANGUAGE

Language used on the course plays an important role. Everything starts from embracing positivity. A lot of feedback is given during the course and it is psychologically important with what tone it is given, in order to conserve creativity. The “I like, I wish” approach is introduced and practiced from day one. It means that giving feedback is brought to the forefront. The feedback is started with wording “I like x” (positive) and ended with “I wish we could make it better in x way” (constructive). The difference to so common negative feedback is quite self-evident, but also using expression “We” builds up a community on every time. Moreover, use of vocabulary like “missions” instead of “assignments” creates an atmosphere that differentiates the course from a regular school. It is significant that every word is thought carefully to serve the purpose of positivity and importance.

RESPONSIBILITY SHIFT

The Figure 8 is a lecture slide demonstrating how the responsibility shifts from the teaching team to the student teams as the project advances. It is important to communicate to the teams that eventually they will have all the responsibility for the course results. The course starts with intense control of teaching team over activities and will shift in relation to time for the students to control of their own project.

ASSESSMENT

In the end, the complex course is graded on a scale from one (poorest) to five (best). In Finland the assessment is effort based to some extend. Questions, like how how far did the team push,, how innovative and successful was the final prototype, are taken into consideration when evaluating how well does the prototype fulfill its purpose and the promises made. It is also evaluated how local and global project team managed the project together. The documentation serves as a tool for the team to explain the prototype understandably Most of the times the members of the group are given the same grade. [11]

In comparison, in the assessment at Stanford University focuses on content and communication. They place equal value (50/50) on the design-outcome (content) and the communication of that content in oral and written form. The teaching team gives a numeric grade of between 0-5 for content and separately for communication. Where grade 5 is beyond expectations and 4 is the same as A. Then the communication and delivery of the project is similarly graded with a 5 for beyond expectations, and 4 for an "A". The course is taught with the expectation that all teams will achieve an "A." All members of the team receive the same grade [3].

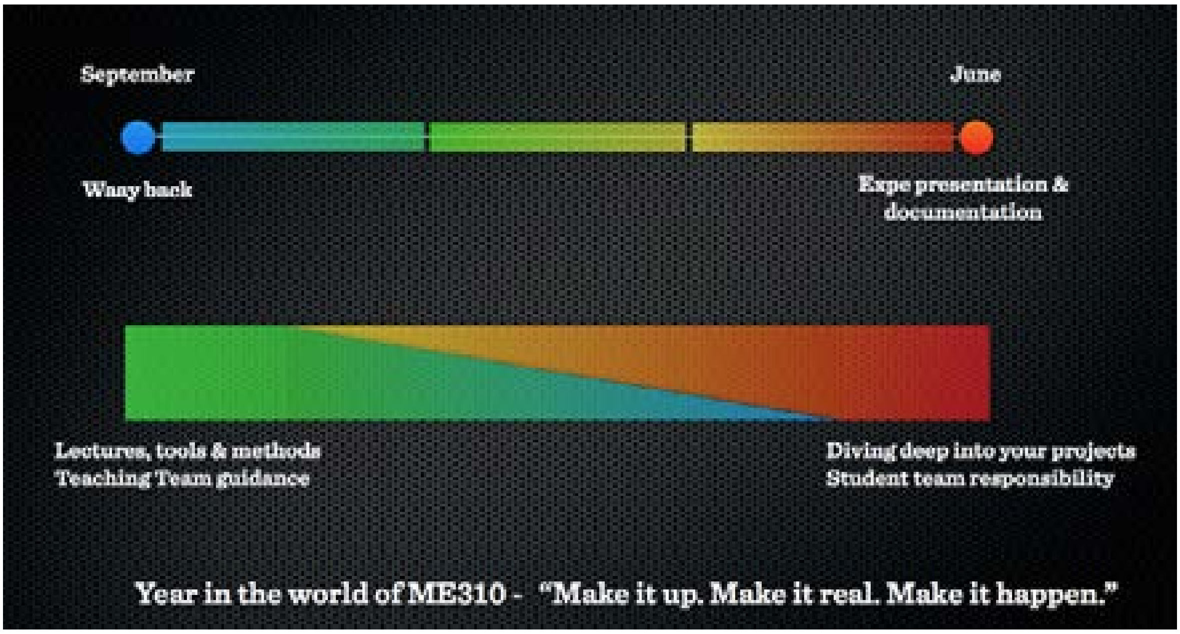

Figure 8 Responsibility shift. (source: teaching material of ME310 course 2012)

3.2 Methods and Data Collection

The starting point of this research was to elicit information from alumni about what working life skills, learned during ME310 Course, they have gained and presently see relevant for their work. Finnish universities have taught the course since 2005, while the course has been running since year 1967 in Stanford University. As disclosed earlier in this study, during almost a decade, 99 students have gone through ME310 course in Finland. The most recent class of 2012, which of the researcher himself is also part of, was used both for the pre-questionnaire and the two prototype interviews. The alumni involved represented disciplines from all the six different schools of the present Aalto University. It was seen important to gather opinions also from other fields than engineering in order to understand fully the general view of the topic. The pre-questionnaire examines the themes, and semi-structured interviews were seen as the best method suitable for exploring perceptions and opinions that might be about complex and personal topics. They also provide a chance for the interviewer to clarify answers and probe new information based on the discussions.

3.2.1 Pre-questionnaire: Setting the Themes

During the late spring 2013, the researcher formulated a question for the present class of ME310 ME310 in order to find themes that could be extracted for further, more detailed studying.. The researcher sent out the question:

> *"Would you please help a me a bit and share some unexpected learning outcome you've had from the course so far?"*

The "unexpected" learning outcomes were explicitly sought since the researcher could derive the most obvious themes from the course by himself. The assumption was that most interesting learning results would be the ones student had not expected to have. By this time, the participants had almost gone through the whole process of the course. Thirteen (13) responses were received and through them the researcher was able to define the themes for interview questions. The themes extracted from the pre-questionnaire can be seen in Table 2 in the results section.

3.2.2 Interviews

The preliminary thought while choosing the individual alumni to be interviewed was to find as encompassing a group as possible in terms of discipline and timeframe. Altogether seventeen (17) alumni were interviewed, including two prototype interviews after which the questions were improved. These prototype interview results were excluded from the data set in order to ensure the consistency and comparative quality of the data obtained. The course started with one team in 2005 and only one person from that team was able to come to the interview. From all the other classes there were two people interviewed, except for year 2011 when there was no course organised due to administrative difficulties in the freshly founded Aalto University. In the very end, the interviews were targeted to fifteen (15) ME310-alumni that took part in the course one to eight years ago as a part of their curriculum in their studies at Finnish universities: Helsinki University of Technology, Helsinki School of economics and Helsinki School of Art and Design, which subsequently merged into one - Aalto University - in 2010. The demographics of the interviews can be seen in the appendix section.

These interviews were conducted retrospectively, during a four-month period from June to August 2013, to find out the long-term effects of the course. The interview questions were open by nature and tried to cover all the key areas of learning in as versatile a way as possible. The researcher had the questions ready, but the topics were allowed to flow from one to another as a natural stream. All the questions weren't answered in all the the interviews. On the other hand extra questions came up in some of the interviews due to interesting topics unfolding from the answers of the interviewee.. These results are presented later in the 'Results' section.

The questions used as a structure in the interviews can be found in the appendices. The interviewed alumni were of two different nationalities: Finnish and Serbian (14 + 1). The language of the interviews was Finnish with the Finns and English with other nationality. The results have been interpreted and translated from the original language to English in order to benefit a more international audience?

In addition to the alumni student perspective of the course, four previous and present teaching team members were interviewed in order to understand how the course is structured and why, and through that find out the best practices translatable to other similar courses.

3.3 Analysis and Limitations of the Methods

The themes that came up from several data points were listed after which more detailed results were categorized under these themes. It is important to recognise several limitations to the data.. All interview responses are opinions of individuals, and older memories are subject to the vagaries of time. The research is qualitative by nature and it does not accurately represent the entire population of ME310, but should be enough to cover differences caused by alternating teaching faculty and to generalise the learning of the individuals to more abstract level.

4 Results

Keeping in mind the main research question about the learning outcomes that alumni have understood retrospectively after the course, the researcher has organised the Results section by introducing the themes of questions derived from the pre-questionnaire in Table 2, which is opened in more detail in the Methods section. The section continues with aggregated results of the interviews with the researcher's comments and illustrated with quotations from the answers to the semi-structured interviews. The meanings, implications of the answers and reflections against the theory are then discussed in more detail in the discussion section.

Table 2 Pre-questionnaire themes

TRUST
DECISION MAKING
COMMUNICATIONS
SELF-DISCOVERY / PERSONAL GROWTH
WORKING METHODS
DEVELOPMENT OF GROUP WORK
PROJECT MANAGEMENT
ENTREPRENEURSHIP
ARGUMENTATION SKILLS
DOCUMENTATION
INTERNATIONAL <-CULTURAL
CROSS-DISCIPLINARITY
SKILLS
ASSESSMENT
USER CENTRIC DESIGN
PROTOTYPING
TESTING
ATTITUDE (TOWARDS FAILING)
FEEDBACK OF THE COURSE

4.1 Learning Outcomes Structured in Categories

The findings from the semi–structured thematic interviews are divided under the four categories that have arisen from the analysis of the conducted interviews. The preliminary analysis begins in this section and possible implications and qualitative analysis is discussed in the “Discussion” section.

1. Communication - team dynamics, cross-cultural, and multiple disciplinarity

Students found out that communication is not an easy task and it is a team effort to build a mutual understanding. Keeping knowledge to oneself does not take the project forward. All the means that make communications easier were seen worth learning.

“One should communicate one’s work to the rest of the group in order to contribute to the group’s total knowledge.”

“Understanding that everyone does not understand your work no matter how carefully you explain. And I also learned what is necessary in communications and what is not.”

“Importance of visuals in communications.”

Remote work is a difficult thing and it sets certain practical limitations to the working hours and ways of working. It also hides people’s real feelings and it is easy to misunderstand what is happening behind the scenes. Remote work is practised quite heavily on the course and and as a result students have enhanced skills to also deal with the related issues:

“Understanding limitations and the slow pace of distant work.”

“[I] learnt how to deal with the short time of communications between Stanford and Europe, also learnt how to solve conflicts and to understand how mad or upset somebody really is” ***ME310 Alumnus***

While it is easy in normal classroom settings and exercises to define the problem and receive straightforward guidance, it is not always the case in working life. There might be a lot of (contradictory) opinions and everyone tries to pull you to their direction:

“In the real world there are contradictions within the stakeholders. I gained skills and experience of how to work out these.” ***ME310 Alumnus***

While it takes quite a lot of work to master international communication, the course tends to give a lot of opportunities to practise communication and to find out new ways to express oneself, especially in an international and intense context:

“In the real world there are contradictions between the stakeholders. I gained skills and experience on how to work them out..” ***ME310 Alumnus***

“[The course’s] teamwork is very different from the teamwork I have done before. Not only because people are from different backgrounds but because the commitment is different”

“Show rather than tell”

“I expected to learn interdisciplinary communication, but I didn’t expect it to be this hard, adding cultural differences and communication with international counterparts, it can easily be one of the hardest projects I have done in terms of how the process went, but it is also the project that triggered the most of self-discovery, through this experience, I know more about what I am good at and what I need to improve“ ***ME310 Alumnus***

The communication is the single biggest theme that comes up in all the interviews. For example, communication was seen as the biggest area of development. Communication included e-tools [email, Google Hangouts, Google Drive, doodle, Trello, Flowdock etc], cultural communication, communication inside the team and to all the stakeholders, and communication between the teaching team and the students. Practical limitations like time differences, and remote working all affected the level and depth of communication. The communication is the first of the four main themes that came up, the second being Self-discovery, which is presented next.

2. Self–Discovery - Personal Growth, Working Methods, Project Management, Development of Group Work

It is typical to feel ambiguous throughout the course. In opposition to traditional teaching, the lack of clear goal setting by the faculty and unannounced structure of the course, unfolding little by little, made many of the students unsure of what level of performance was actually expected from them.. Coping with this feeling and going forward with the project was difficult. The lack of structure and being pushed out of one's comfort zones are important elements of the course. For some students it was more difficult to understand that tolerating ambiguity is one of the intended learning outcomes. Of course, encouraging examples from previous classes were given as stories to set the level of the prototype resolution and innovativeness.

For many ME310 alumni the course has been a life changing experience and they have been able to validate what they really want to do and not to do in their life:

"I want to work with people with great ambitions and the ability to be outside my comfort zone"
"Prioritising what one wants to do and with whom. Courage to hunt for what I really want." ***ME310 Alumnus***

It was also very clear that working with the best and succeeding will boost one's self-confidence to a new level:

"Everything is possible, no limits in the world."

"Understanding that I am on the same line with the best students of the world" ***ME310 Alumnus***

It was also important to learn what the real drivers of the people were, since sometimes it might not be that clear:

"Understanding what were the drivers of doing good job, such as personal promises, end goal, own ambitions, work and time committed already, owning the product, not the external carrots (in this case: study credits)" ***ME310 Alumnus***

3. Design Process (user-centric design) - prototyping, testing, decision making

The difference between seeing users in action and talking to users versus reading about them and using second-hand knowledge was learnt to be significant. Some of the students experienced this in a concrete way by going to the field. The imagined user did not exist..

"Learnt to apply user centric design a little bit, but it seems to be a much more complicated matter than suggested on the course."

"Questions work well in incremental product development, but users don't know what they want"

"Got understanding of the real user instead of imagined one by going to the Audi club meeting"

Making ideas tangible and proving your learning to yourself and to the team, by creating a prototype, were understood on a deep level. Some of ME310 course alumni even claimed that they have practised the design process thoroughly:

"Learned to master an open-ended early stage project and apply design process to it"

An essential finding for alumni was that all the ideas might be valuable and how prototyping them works in order to validate them:

"See the goodness in crazy ideas too."

"Ideation process is never finished. Learned to stop and not to focus on details in too early phase of prototyping."

"[Learned] not to rank out ideas at first hand, but to test and validate them. You never know where the value lies." ***ME310 Alumnus***

In addition, the course teaches to find the ideas from everywhere:

"Learned to seek dead-ends and go hunting for needs"

"Everything is a prototype – e.g. a lecture" ***ME310 Alumnus***

In addition, the students seemed to learn what they often described as hard things, like saying no:

"Learn to abandon ideas"

Interestingly the frequent cycle of the design process enables students to make a lot of decisions and through that learn about decision-making:

"It is important to make decisions; even wrong ones bearing in mind the decision makers ultimately have the responsibility"
"Make small decisions by intuition and others based on test results."
"Prototype decides it for you"
"Even if you make the decision now, you can change it later without any shame. Failures happen."
"Making a good decision today is better than making a perfect one tomorrow"
ME310 Alumnus

Students also realised how the biased settings could possibly affect the test results:

"The problem is that you always get the answers you predetermined if you pick the questions right."

This quotation is excellent proof of how the process is highly valued among the alumni:

"A key learning outcome from the course for me was the user-centric approach to design. It's not about becoming an expert in a certain field (i.e. automotive, gaming, tech, wood industry) but rather learning a process that can be applied to a multitude of situations. That's the key of teaching the IDEO circle process... to become versatile designers that can parachute into any scenario, apply the approach and a set of tools and produce innovative ideas effectively and efficiently."
ME310 Alumnus

4. Mindsets - Attitude towards Failing, Entrepreneurship

"Before I believed that everything should follow certain rules, but after ME310 I understood that you can create your own rules!" ***ME310 Alumnus***

"Put up with that everything is at risk." ***ME310 Alumnus***

"Put up with that everything is on the line of risk." ***ME310 Alumnus***

"Doing things with more courage and being independent." ***ME310 Alumnus***

The course had also changed the attitudes of the alumni and it was hard for them to see failure as a negative matter anymore but actually the opposite:

"Nothing is actually failing, more like an opportunity to learn." ***ME310 Alumnus***

It is not rare that an ME310 Alumni will end up as an entrepreneur. A lot of them saw the ME310 had a leading role in this decision to start their own company:

“Feeling more secure about entrepreneurship”
“From an image of alcoholic convenient store keeper to super cool profession”
“The course exhales entrepreneurship.”
“[Attitude changed] From very negative to very possible option” ***ME310 Alumnus***

The ambiguity and the process seems to help in this choice of career:

“Gives readiness for being an entrepreneur.“
“[I] like ambiguity and freedom.” ***ME310 Alumnus***

Futhermore, an alumnus who had become an entrepreneur found it beneficial to recall some of the experiences from ME310 course:

“You can always draw confidence from the course while being an entrepreneur who is naturally not getting too much feedback.” ***ME310 Alumnus***

Looking at the intended learning outcomes for the course, the Self-Discovery and Mindset are of the highest level of personal growth. The students feel that these learning results have changed them the most. Considering that the ME310 alumni have been in working life already for several years, this makes the claim highly valid, important and valuable.

4.2 Anticipated Learning Outcome by Prospective Students

The students who apply for ME310 course have normally somehow interacted with the previous students. Either they personally know someone from the course or they have spent time in Aalto Design Factory due to another course, and thus seen people taking the course. They might have been encouraged to take the course and heard positive feedback. The view of the course is based on the whole brand of the course and clearly it is seen to be more than just a course.

Prospective students had seen the community, the fun side and the traveling included in the course and mainly mentioned that they applied because of that. In addition, strong brands were mentioned, such as Audi and Stanford. Only a fraction of the applicants had applied with learning of design thinking, Stanford methods, and problem based learning in mind. Some expressed that they would like to learn to prototype more and get their hands dirty unlike on their earlier courses.

Surprisingly enough the applicants had not done their background research on what they were applying to do for the next nine moths.. They had not even gone through the previous projects. Based on the interviews, the teaching team was worried that people did not know what they are applying for and how would they like to benefit from the course.. One solution for this, suggested by the teaching team, might be to advertise the fun side of the course less prominently.

4.3 Best Practices of the Course

The secondary research question was to to seek the best practices from the course pedagogics on a level that is transferable. Underlying reason to disseminate research-based information, is to assure it is appropriately considered for use in reaching decisions, making changes, or taking other specific actions designed to improve outcomes. The goal for dissemination is utilisation. Generally, the information provided must include details of content, context, and resources needed before implementation can be planned in sufficient detail. The section three (3) of this thesis provided the context and this section will take a stance on content and resources.

The best practices were asked from the teaching team explicitly and also extracted and interpreted from the interviews conducted. [11][15][16][17]

1. The application interviews should be organised, if the course is compelling enough.
2. SUDS, “i.e. slightly unorganised design sessions”, is a way for students and faculty to get to know each other better and to create an atmosphere that encourage students towards creativity. Making fun things time to time. Work and play.
3. Building prototypes early on.
4. Students should be challenged first with something enjoyable and unfamiliar in order to expand their comfort zone gradually.
5. Communicating that students are valued by the teaching team.
   This can be expressed in various ways, for example by staying late with students, paying attention and asking what they do, making an effort to provide feedback. In general: putting the students in the centre of the process.

6. Providing helpful staff that is always there with a good attitude. Concretely this means taking attitude that there are no stupid questions, and a supporting environment for doing and testing.
7. Providing a lot of freedom, starting from the design briefs, but also building a structure of process where students can get safety from.
8. Building exercises: paper bike or paperbot (explained in more detail in the section three). Exercises act as means to find the team spirit quickly and provide introduction to building.
9. A subtle facilitation during the course by examples and questions like: “look what the other group has done”.
10. Roleplaying within the teaching team: who is giving which kind of feedback. Using time for preparing for the feedback sessions.
11. I wish – I like – approach for feedback through positive attitude. The goal is to always come out of a small group meeting with a positive attitude: something has been learned and something can be done better next time.
12. Never giving directions for the content, only for the process. This means never making the decision for the team, but always leaving the ultimate decision making to the students. Questions like: “is it answering your question?” force the students to take the whole responsibility. Be also prepared to have a hard time not intervening as an instructor since you might have your own opinions about the direction of the project.
13. Instruct corporate liaisons not to define too precisely what they want out of the project.
14. Observing, and if needed helping with different practical things - if stuck with brainstorming – help, if building is a problem – help.
15. Teach students the basics of time management if they are lacking that skill.
16. Teach to build to think approach rather than think to build. [15]
17. Use resources for team building.
18. Team-Roulette; give a group’s challenge to another group inside the classroom, or change some of the members for one day.
19. Give similar relatable contexts, in other words show examples. Keep the students focused on small steps enough until they grasp the whole process. Act as a moderator in their process with appropriate pace.
20. Organise the course in order to avoid getting stuck on one prototype for too long. The business cycle of two to four weeks seems appropriate based on the course development.
21. Having mid-presentations force students to formulate their thinking on the way to the final prototype. Time invested in presentations advances the project.

22. In order to make the deadlines credible enough, the teaching team should focus resources to invite large enough venue and crowd with some experts for each of the presentations. That makes students feel special and raises the value of the occasions, which is relative to the motivation and working hours students put in the presentations. Take the presentation rehearsals very seriously since good rehearsals prepare for good presentations.
23. Teaching brainstorming techniques and how to draw good results from them: practise developing the prompt – the question brainstormed. This can be done as a group-brainstorming with the whole class. Especially important is to encourage positive, build on others' ideas, and make things visual. After brainstorming, group, vote on and revisit the ideas.

4.4 Development Suggestions for the Following Courses

In the interviews the students were also given an opportunity to express their development suggestions of the course based on their experience. Development suggestions based on feedback is suggested in Discussion section. In this section, the the voice of interviewees is heard for:

"Communicate the goals of the course."

"Would need more sessions of actually teaching some skills, machining, communicating, bluefoam cutting/basic prototyping"

"Emphasised trying things out before deadlines, but then there was no emotional processing afterwards why this prototype failed. That's why no real failures were experienced."

"Ideas were identified to the louder speaking students"

"As an alumnus, there was no connection to the course this year."

"Reflection of the group's processes, what led to better results in different groups what did not work?"

"Style of the feedback maybe too black and white"

"Take all the stakeholders within the communications, i.e. Stanford teaching team, in order to prevent communication issues to arise."

“Making visible, which of the results were put to use in in the companies.”

“Testing, and quality and quantity of testing should be more appreciated on the course. (maybe minimum requirements for testing?) Emphasise the importance of learning how and why to pick questions, subjects and settings as well as the importance of making and building.”

“Should the course target somewhere else than gimmick level experience at the EXPE or more sustainable products that could be commercialised in the long run?”

“Give the feedback [about the documentation] when it is still possibility to have an affect on the result”

“Try to fit it (the course) in study programs [in order to ensure time usage]. How much you get from the course is in relation to how much you put in.”

“Also others than engineers should get discipline related support.”

“100 page report does not help learning”

“Tell explicitly that this is an engineering course”

“Use checkpoints where business students have to contribute too”

“Include team building teaching to the class. Teach to do “I wish - I like” within the group orally, too.”

“Develop the presentations to be more entertaining earlier on than in the very end.”

“Use some kind of length limit in the documentation”

“Add an option to vote team members out.“

“Let the company know that it is very important that the students understand quickly the brief”

“Have a workshop with the students and the liaison after a month after the design briefs are given to ponder the brief thoroughly.”

“Organise a liaison training for liaisons to understand the best way to participate to the course”

“Teach small crash courses on coding iPhone, Android, making web sites”

“Is there a way to visualise it [design requirements] and be more understandable. “

“Make us understand the benefit of user-test.”

4.5 View of the Company Liaisons

Two different liaisons were interviewed, who do not want their names to be published, about their experience of the course as a liaison. They talked about the reasons the companies join in the projects and what are their expectations of the results of the course.

Liaisons saw the work with student very beneficial for the company since it receives a lot of new, tested ideas. They also saw the design brief as the most important tool they use. The way they formulate the brief together with the teaching team, is relative to the results they get. The attitude towards students was extremely positive and they have a belief that the students are among the people who can change the world for better. Desire to innovate was seen as the most substantial reason for joining the course. Ideas were expected to be delivered in the form of various prototypes. The students were considered as a resource that can deliver ideas that the company is unable to invent by themselves. While the price of joining the course was seen high, the benefits were still considered to be greater. In addition, an obvious reason to participate in the course from a company perspective was the access and the possibility to recruit some of the best young talents in the world.

5 Discussion

University students need to acquire thinking and working skills to tackle ill-defined challenges, but their education often leaves them under-equipped to do so [36]. Based on the results of the ME310 interviews, this course is taking a stand for solving this problem. The final outcome of this study is a compilation of learning outcomes that are validated by alumni through experiences of their working career. This section is intended to analyse and discuss the results of the interviews in the light of the theory presented previously in this study, examine the implications of the findings and draw conclusions and make suggestions based on them. Recommendations for the Intended Learning Outcomes (ILOs) are founded on the interviews, and the best practises of the course are construed in order to share them in a clear format. Comparing the expectations of prospective students to the learning outcomes can be used to develop the image of the course to be more realistic.

5.1 Design Thinking

The theory discusses design thinking where it is seen as a controversial topic without a clear definition [20]. In this study I use the definition by Tim Brown, the CEO of IDEO company that is where the ME310 course originates. In perspective of a complete product development strategy, it is a discipline that uses the designer's sensibility and methods to match people's needs with what is technologically feasible and what a viable business strategy can convert into customer value and market opportunity. It is also a blend of methodologies, work practices, culture and infrastructure, which is why it is so hard to describe it explicitly. [30] In ME310 context, these methodologies include such elements as the designer tools that are taught (user persona, gaining user empathy, foresight tools, etc. [104]), prototyping, mindsets and all the support given to the students in order to help to build and think.

The results presented earlier illustrate that design thinking [37] practices, cognitive approaches, and mindsets all have positive influence for enhancing learning results for engineering students. Design thinking literature emphasises the importance of collaboration with people from other disciplines in order to design complex solutions. Interdisciplinary teams and open-ended design briefs support this goal in ME310. The results show that especially learning results in the area of working life skills [41] such as project-based teamwork, communication and problem-solving skills, were improved during the course. In addition, self-discovery, understanding of the importance of different practices such as prototyping and the students' entrepreneurial mindset increased. In short, the students go through a significant process of personal growth if they have committed themselves to the course. The students have achieved multiple learning levels and are able to learn from each other and at the same time they are able to clarify their own knowledge and skills for themselves and for the other team members, as seen in the Communications theme group of the results introduced earlier.

One of the most important tools for experimenting and searching for solutions is prototyping [28] in various ways and from early on. One aspect that surfaces in various sources is user-centricity [e.g. 33,34,37] and therefore testing ones ideas and prototypes with users can be stated to be of importance as well. The course structure stresses the importance of creating multiple new solutions to choose from instead of choosing from existing alternatives or creating only one solution to a problem [26,29,28]. The outcome of experimenting and going through rounds of trial and error should be learning and identifying directions for the process - which might not have been taken otherwise – while aiming for a significantly new solution to a problem by questioning what is already known [33]. Therefore the nature of solving open-ended problems requires disregarding the fear of failure [34], acceptance of ambiguity [25,37] as well as the ability to reflect in action [21].

5.2 Problem-based Learning

It is more and more important that engineers master a combination of disparate capabilities – not only technical competencies concerning problem solving and the production and innovation of technology, but also interdisciplinary skills of cooperation, communication, project management and lifelong learning abilities in diverse social, cultural and globalised contexts. [42][46] This is exactly the context where ME310 is situated.

In ME310, self-directed learning (SDL) is manifested in needfinding and benchmarking phase, but also every time the team chooses to prototype some of the ideas. In ME310, the approach differs from PBL where the knowledge is always context-dependant and the idea is to find the needs that are not general but very specific to the user-scenario. During this phase students decide among themselves what they need to know about the topic of their problem and return with this information.

In PBL, students become responsible for their own learning, which necessitates reflective, critical thinking about what is being learned [51, 52]. In the course, each group stops every week to reflect upon what they have learnt and critically evaluate the choice of the next direction of the project. Explaining one’s ideas is important for productive collaboration and also serves to enhance learning [63]. In ME310 pedagogy, prototyping is used to explain and express ideas. Reflection has a less significant role in ME310 than PBL suggests, but documentations acts as the main reflection tool.

ME310 uses word 'mission' every time when building some kind of prototype, or part of it. During these missions, the students figure out themselves what they will build, and they have find it very motivating. Each of the prototyping round will last two to four weeks so the goal is really concrete while the final proof-of-concept prototype acts as an umbrella for motivation since all the prototypes serve the purpose of finding the final one.

It is also mentioned that PBL might not be a sufficient approach to a whole education program in engineering since the nature of engineering knowledge is quite hierarchical and a failure to understand or overlook some of the concepts may have been impossible to correct during studying only through PBL methodology. [42] On the other hand, the results of this study suggest that this kind of course would work well as a last integrative, capstone course which applies, challenges and brings together everything learnt so far at the university.

5.3 Self-discovery and Entrepreneurship

Skills and competencies are developed while students work in teams, and through the process students discover much about themselves, thus giving a more realistic view about their own self-image. The methodology cultivates a spirit of investigation and innovation, creativity for the generation of new knowledge, productive thought, and motivation to learn and solve problems. [46].

The result of positivity in 'failing fast' mindset is consistent with research that demonstrated that as people are first attempting to apply new knowledge, they do not always do it well [75][76]. Theory suggests that errors are necessary steps in learning to apply new knowledge. By articulating incorrect knowledge, learners have the opportunity to revise their false beliefs when they are confronted with correct knowledge. [77] This leads to the resulted behaviour of seeing failing as a method of learning.

The theory was able to predict most of the learning, but not the depth of the self-discovery and mindsets. The results of this study showed some evidence that the course improves attitude towards entrepreneurship. Many of the alumni are researchers or entrepreneurs which is a finding itself.

5.4 The Best Practices

The implementation of the course is another aspect to consider. ME310 has a long development history and an alumni network that can be utilised both in course subjects and more importantly in teaching team formation. Communication inside and to the students from the teaching team is of paramount importance to learning. For the students to be able to go through the process of tolerating ambiguity, the teaching team must support them. Not by giving answers but by being present, making the right questions and also by encouraging the students to go forward despite the ill-defined situation. The teaching team should build the confidence of the students by shifting the responsibility of the projects little by little to the students and eventually let go and let the students shine. We all have a creative side, but we need a culture encouraging it, tolerating occasional failure, and embracing risks and wild ideas. Failing fast and hence succeeding faster necessitates that there is a safe and supportive environment for failure, which is built since the beginning of the course.

In ME310, extra effort, such as informal activities and continuous presence of the teaching team, is made in order to create a sense of a community among the students and the faculty. As Haslam states, identifying themselves as a part of a larger group impacts group's willingness to maintain commitment [39]. This can be seen in the very end of the course, where there is an extra mile to be walked in order to finish the prototypes. The countless working hours put in at that stage of the project communicates the commitment of the whole student community.

It is interesting to understand how the positivity is created inside the classroom. It seems that the culture and the ways of working depersonalise anyone who would in another setting be seen failing. The whole ideology is honed to a level where all the human aspects of awkwardness are limited and positivity is embraced in order students to be at their most creative. The level of detail stretches even from specific positive language to shaping of the learning environment and organisation. The battle is won as a team and lost as such too. The success of Design Thinking approach is not depending only what you teach, but how you teach it.

5.5 Code of Conduct

In the ME310 course, students learn to cooperate with different nationalities and disciplines and also to understand one's own mindset. The course offers endless possibilities to observe how fellow students from various backgrounds and cultures operate in numerous situations since the course setting is very close to the real world. Mindsets differ from one another and the course acts as platform to recognise these codes before the professional life will commence. This by itself is not enough, but if the faculty should define the desired code of conduct and apply it in the teaching consistently, the desired impact could be achieved.

Interestingly enough, business schools have recently taken the initiative of rethinking what makes a good business manager and the report explains how students in Harvard Business School have started to pledge an ethical oath equivalent to a doctor's Hippocratic Oath [103]. This kind of activity has not been engaged in Aalto University yet, but I would imagine its necessity in the near future when yet more international students apply to the master's degree programs from all over the world with differing codes of conduct. The same principle could be applied in engineering education as well, and added to the learning outcomes acquired after a product innovation course.

5.6 Developed Intended Learning Outcomes for the Course

The course instructor shared in his interview about the learning outcomes that "Students have to be able to think, do new, acquire knowledge, experiment and push boundaries" [16]The ME310 course has been lacking a profound description of what students should learn in this course. Intended learning outcomes should support the philosophy of the teaching: student-centred, learning by doing, emphasis on tangible prototypes and the cyclic nature, do-test-learn, of the course. Literature suggests using Bloom's taxonomy for classifying intended learning outcomes. To recap from the theory, things the teacher should consider while developing learning outcomes are:

a) the kind of knowledge to be learned (declarative or functioning)

b) the content or topic to be learned

c) the level of understanding or performance to be achieved. [102]

The categorising used is the Bloom taxonomy which presented earlier in this study: Remembering, Understanding, Applying, Analysing, Evaluating and Creating. Based on the research done in scope of this thesis reflecting the sections ‘Materials’ and ‘Results’, the following intended learning outcomes are suggested:

UNDERSTANDING

- Is able to explain team’s progress and current state
- Identifies the challenges and potential of remote working
- Identifies failing as a key learning opportunity

APPLYING

- Operates effectively and ethically as a team member in real-life accounting situations
- Demonstrates ability to efficiently communicate and learn through prototypes
- Applies hard skills learned previously in the university to a real-life project as a representative of one’s own discipline

ANALYSING

- Is sensitive towards individual and cultural differences
- Evaluates results of user testing and interprets it to the learning outcome
- Is able to deconstruct system to a controllable components
- Writes documentation about the prototype and the process related

EVALUATING

- Assesses the performance of one’s own and team’s work
- Prioritises and selects the most suitable components for the prototype
- Responds effectively to unexpected experiences and ambiguity

CREATING

- Applies IDEO design process
    - Integrates needs and benchmarks into a valuable cluster of information
    - Generates a problem space based on the needs and creates the solution space accordingly
    - Designs a prototype fulfilling given and discovered requirements
    - Plans manufacturing of proof-of-concept prototype
    - Creates comprehensive experience to present in design fair
- Develops team work skills in an interdisciplinary and multicultural setting

5.7 Development Suggestions for the Course

Even though the evidence of the results shows that the students learn a lot during the course, also the ME310 could be and should be better every year. From the development feedback given can be noticed, some of the goals of the course are not fulfilled each year consistently. There are also possible contradictions between what the course tries to teach and what the alumni have actually learned.

First of all, it is not clear what are the learning outcomes of the course for the students. This study should help the teaching team to communicate the goals of the course better. The learning could be significantly enhanced if time would be invested in reflecting after each mission. Even though there is quite a large alumni base, it could be used more efficiently. At least showing how the results are used in the companies would increase the motivation of the current students.

Building is emphasised quite a lot during the course but the actual user testing is not seen on a sufficient level. Focusing more interest, and teach how to do testing, would make the process more plausible. The angle to the final outcome of the course was also questioned since presenting prototypes that had to function only for a day were seen only relatively vague task instead of making something that could for example be commercialised in the long run.

On practical level, if there were a possibility to receive feedback on the documentations before they are handed in, learning would be more comprehensive. Also some length management should be used since the more compressed information students provide, the more efficiently it will be communicated. As the design requirements are seen really important, figuring out a way to present them more visually would benefit the students' learning.

The credits given after completing the course was criticised. The time used for the course is not corresponding the credits received. The recommendation for the credits granted should be near to what students suppose to study in a year. Even though it is an engineering course originally, it was hoped that everyone could receive support for their disciplines. Creating a larger network of faculty related to the course could solve this problem.

It was also suggested that in order the students really be on the same page with the liaison, some kind of longer time period should be forced to spend with the liaison. Also there was a lot to do with that the new liaisons would understand how the course works. Some kind of training for the liaisons would relieve the tension between the students and the company.

5.8 Future Discussion

The ways students are evaluated can affect students' motivation. The evaluation practices include standards, criteria and method as well as the frequency of evaluation. The students' perception of the meaning and the usage of the evaluative information is the most important aspect. [70] Interestingly, most of the interviewees did not know how they were assessed. Furthermore, having asked from different teaching team members, they have answered in different ways. As the foundation of learning objectives have laid now, it would be interesting to study how to develop and open up learning objectives for the whole engineering degree programme.

6 Conclusions

Question is what should we learn in universities? There is a need of better graduates that are able to work in a globalised environment and develop better sustainable products. There should be persons to take initiative and found companies that the economy would not struggle. If many of ME310 alumni actually orient themselves towards academic research or entrepreneurs, maybe there is something to learn. ME310 uses design thinking and user-centricity as approaches to product development. It became clear that design thinking is not a clear concept that you can just box and define completely, but something that lives and is all around us. It is something we do and practise, not something we can study from books.

The most important findings of my work are divided in four categories: Students learn about others, themselves, tools, and develop certain mindsets. The first one has a lot to do with communications in general. It means that in ME310 students learn through endless conversations in groups, between groups, between group and the teaching team, and between groups overseas. They learn how to communicate across multiple disciplines and learn how to use universal language of prototyping in order to make sure that everyone is speaking about the same thing even though they might use different words.

The second category is more oriented to oneself. A student goes through a significant personal process of learning, emotions and ambiguity. After reflection period, students realise e.g. what they like and what they do not like. They have to grow in contradictory surroundings, which is very typical for designers: there is not a clear framework or solution to the problem at hand. It is an uncontrollable process where students have to learn to manage it, or learn how to let go of it, and trust that there will be a final outcome even though it is still unknown what it will be.

The third category is about the tools that are learned during the course. If the design process is seen as a tool, it is used many times and students learn the basics of prototyping, testing and decision-making. Especially, decision making seems to be very hard in international context, and often face-to-face meetings are highly appreciated after the course.

The fourth category is about mindsets. During the intensive nine-month period of a ME310 course, other things that are not so obvious are developed. The whole class breathes the same air of approval, curiosity, exploration, engaging, and it seems that there is something extraordinary changing in most of the students. The students start to see opportunities where they earlier saw failures. It is a big part of the learning experience to understand how a change in attitude affects the results of the product development. While the alumni report unbelievable boost on their self-confidence and courage, it seems to contribute a great deal to the attitude also needed for an entrepreneurship. Change in attitudes and the fact that many of the alumni becomes an entrepreneur, implies that the course could be used as an incubator to coach entrepreneurs.

7 References

[1] Altbach, Philip G., and Jane Knight. “The internationalization of higher education: Motivations and realities.” Journal of studies in international education 11.3-4 (2007): 290-305.

[2] Fry, Heather, Steve Ketteridge, and Stephanie Marshall, eds. A handbook for teaching and learning in higher education: Enhancing academic practice. Routledge, 2008.

[3] Larry Leifer. Course Instructor of ME310, Stanford University, Interview. 10.06.2013. Stanford, California.

[4] Crawley, Edward, et al. “Rethinking engineering education.” Spring 2 (2007).

[5] Boud, David, and Grahame Feletti, eds. The challenge of problem-based learning. Psychology Press, 1998.

[6] Levander Lena [et al.] Learning Together - towards enhancing the co-creation of education: Aalto Universiry Teaching and Education Evaluation 2010-2011 Project Report [Report]. - Espoo : Aalto University, 2011.

[7] Carleton T., Leifer, L., “Stanford’s ME310 Course as an Evolution of Engineering Design”, Proceedings of the 19th CIRP Design Conference – Competitive Design, Cranfield University, 30-31 March 2009, pp547.

[8] Kauppi, J., Insinööritieteiden opinto-opas 2013-2014: Diplomi-insinöörin tutkinto [Book]. - Helsinki : Unigrafia Oy, 2013. P. 104-105

[9] Stanford curriculum, Retrieved August 10, 2013. https://explorecourses.stanford.edu/

[10] ME310 Website by Aalto University. (2013). Retrieved April 9, 2014, http://me310.aalto.fi/apply-now/

[11] Interview. Tuomas Sahramaa, Teaching Assistant. 28.8.2013. Helsinki.

[12] PechaKucha (2013). Retrieved August 10, 2013, http://en.wikipedia.org/wiki/PechaKucha

[13] T. Björklund, S. Luukkonen, M. Clavert, S. Kirjavainen, & M. Laakso, “Aalto University Design Factory through the eyes of its community members”. 2011.

[14] Ekman, K., Aalto Design Factory, Annual Publication 2012-2013 (2013), p.5.

[15] Harri toivonen, Teaching Assistant. Interview. 12.08.2013. Espoo.

[16] Lauri Repokari, Course Instructor. Interview. 16.08.2013. Espoo.

[17] Tuuli Utriainen, Teaching Assistant. Interview. 06.08.2013. Espoo.

[18] Aalto University,“ME310 course brochure”, https://noppa.aalto.fi/ , 2013.

[19] S. Kirjavainen, & T.A. Björklund, “The central role of exploration in designing business concepts and strategy”, Proceedings of The 18th International Conference on Engineering Design, ICED. 2011.

[20] L. Kimbell, “Beyond design thinking: Design-as-practice and designs-in-practice”, Paper presented at the CRESC Conference, Manchester. 2009.

[21] D.A. Schön, “The reflective practitioner – How professionals think in action” (2nd edition) Aldershot: Ashgate Publishing Ltd. 1991.

[22] H.A. Simon, H. A. “The Sciences of the Artificial”, Cambridge: MIT Press. 1969.

[23] L. Hassi, & M. Laakso, “Design Thinking in the management discourse: Defining the elements of the concept”, Proceedings of The 18th International Product Development management Conference, IPDMC. 2011.

[24] U. Johansson, & J. Woodilla, “How to avoid throwing the baby out with the bath water: An ironic perspective on design thinking”, EGOS Colloquim 2010: June 30 – July 3, Lisbon, Portugal. 2010.

[25] N. Cross, “Designerly ways of knowing”, Berlin: Springer. 2006.

[26] B. Lawson, “How Designers think – The design process demystified” (4th edition), Oxford: Architectural Press. 2005.

[27] H.A. Simon, “The sciences of the artificial” (2nd edition), Cambridge: The MIT Press. 1981.

[28] T. Brown, “Change by design: How design thinking transforms organizations and inspires innovation”, Harper Business. 2009.

[29] R. Martin, “The design of business: Why design thinking is the next competitive advantage”, Boston: Harvard Business Press. 2009.

[30] Kelley, Tom & Littman, Jonathan. The Art of Innovation: Lessons in Creativity from IDEO, America’s Leading Design Firm. USA, 2001. 308 s. ISBN 0-385-49984-1.

[31] R. Coyne, “Wicked problems revisited”. Design studies, 2005, 26, 1, p.5-17.

[32] R. Buchanan, “Wicked problems in design thinking”, Design Issues,1992, 8, 2, p.5–21.

[33] T. Brown, “Design thinking”, Harvard business review, 2008, June, 84-92.

[34] D. Dunne, & R. Martin, “Design thinking and how it will change management education: An interview and discussion”, Academy of Management Learning & Education, 2006, 5(4), 512-523.

[35] C. Owen, “Design thinking: Notes on its nature and use”, Design Reseach Quarterly, 2006, 2(1), 16-27.

[36] M. Laakso, & M. Clavert, “Promoting creativity and design thinking skills among university students”, Manuscript accepted for publication in: Bas, E. & Guilló, M. (eds.). INJUVE Special Issue on “Youth and Future Images”. In press.

[37] R. Martin, “How successful leaders think”. Harvard business review, 2007, June, 60-67.

[38] Brown, R. Group processes: Dynamics within and between groups. Basil Blackwell, 1988.

[39] Haslam, S. Alexander, et al. “Sticking to our guns: Social identity as a basis for the maintenance of commitment to faltering organizational projects.” Journal of Organizational Behavior 27.5 (2006): 607-628.

[40] Felder, Richard M.; Silverman, Linda K. Learning and teaching styles in engineering education. Engineering education, 1988, 78.7: 674-681.)

[41] K. Michlewski, “Uncovering design attitude: Inside the culture of designers”, Organization Studies, 2008, 29(3), 373-392.

[42] Mills, J.E. et al. Engineering education—Is problem-based or project-based learning the answer?. Australasian Journal of Engineering Education, 2003, 3: 2-16.

[43] R. Henshaw, 1991, “Desirable attributes for professional engineers”, Broadening Horizons of Engineering Education, 3rd Annual conference of Australasian Association for Engineering Education, pp. 15.,

[44] J.D. Lang, Susan Cruse, Francis D. McVey, and John McMasters. “Industry expectations of new engineers: A survey to assist curriculum designers.” Journal of Engineering Education 88, no. 1 (1999): 43-51.)

[45] A.Kolmos,. “Future engineering skills, knowledge, and identity.” Engineering science, skills, and bildung (2006): 165-185.

[46] Ríos, Ignacio de los, et al. Project–based learning in engineering higher education: two decades of teaching competences in real environments. Procedia-Social and Behavioral Sciences, 2010, 2.2: 1368-1378.

[47] F. Moti, I. Lavy & D. Elata. “Implementing the project-based learning approach in an academic engineering course.” International Journal of Technology and Design Education 13, no. 3 (2003): 273-288.

[48] J. Krajcik, C. Czerniak & C. Berger, “Teaching children science: A project-based approach. Boston: McGraw-Hill. 1999

[49] J.C.Perrenet, P.A.J. Bouhuijs, J. G. M. M. Smits, “The suitability of problem-based learning for engineering education: theory and practice.” Teaching in higher education, 2000, 5.3: 345-358.

[50] Hmelo-Silver, Cindy E. “Problem-based learning: What and how do students learn?.” Educational Psychology Review 16, no. 3 (2004): 235-266.

[51] Bereiter, Carl, and Marlene Scardamalia. “Intentional learning as a goal of instruction.” Knowing, learning, and instruction: Essays in honor of Robert Glaser (1989): 361-392.

[52] Resnick, Lauren B. Knowing, learning, and instruction: Essays in honor of Robert Glaser. Lawrence Erlbaum Associates, Inc, 1989.

[53] Schmidt, Henk G., Maurice L. De Volder, Willem S. De Grave, Jos HC Moust, and Vimla L. Patel. “Explanatory models in the processing of science text: The role of prior knowledge activation through small-group discussion.” Journal of Educational Psychology 81, no. 4 (1989): 610.

[54] Bransford, John D., and Nancy S. McCarrell. “A sketch of a cognitive approach to comprehension: Some thoughts about understanding what it means to comprehend.” (1974).

[55] Johnson-Laird, Philip Nicholas, and Peter Cathcart Wason, eds. Thinking: Readings in cognitive science. CUP Archive, 1977.

[56] Kolodner, Janet L. “Educational implications of analogy: A view from case-based reasoning.” American Psychologist 52, no. 1 (1997): 57.

[57] Kolodner, Janet L., Cindy E. Hmelo, and N. Hari Narayanan. “Problem-based learning meets case-based reasoning.” In Proceedings of the 1996 international conference on Learning sciences, pp. 188-195. International Society of the Learning Sciences, 1996.

[58] Hmelo, C. E., and Lin, X. (2000). The development of self-directed learning strategies in problem-based learning. In Evensen, D., and Hmelo, C. E. (eds.), Problem-Based Learning: Research Perspectives on Learning Interactions, Erlbaum, Mahwah, NJ, pp. 227–250.

[59] Zimmerman, Barry J. Becoming a self-regulated learner: An overview. Theory into practice, 2002, 41.2: 64-70.

[60] Barron, Brigid. “Achieving coordination in collaborative problem-solving groups.” The Journal of the Learning Sciences 9, no. 4 (2000): 403-436.

[61] Cohen, Elizabeth G. “Restructuring the classroom: Conditions for productive small groups.” Review of educational research 64, no. 1 (1994): 1-35.

[62] Wenger, Etienne. Communities of practice: Learning, meaning, and identity. Cambridge university press, 1998.

[63] Webb, Noreen M., and Annemarie Sullivan Palincsar. “Group processes in the classroom.” (1996).

[64] Dahlgren, M. Abrandt; Dahlgren, Lars-Ove. Portraits of PBL: Students’ experiences of the characteristics of problem-based learning in physiotherapy, computer engineering and psychology. Instructional Science, 2002, 30.2: 111-127.

[65] Evensen, Dorothy H.; Salisbury-Glennon, Jill D.; Glenn, Jerry. A qualitative study of six medical students in a problem-based curriculum: Toward a situated model of self-regulation. Journal of Educational Psychology, 2001, 93.4: 659.

[66] Ferrari, Michel, and Ram Mahalingam. “Peersonal cognitive development and its implications for teaching and learning.” Educational Psychologist 33, no. 1 (1998): 35-44.

[67] Leontjev, Aleksie Nikolaevich. “Activity. consciousness. personality.” (1978).

[68] Bandura, Albert. “Self-efficacy: The exercise of control.” (1997).

[69] Dweck, Carol S. “Self-theories and goals: Their role in motivation, personality, and development.” In Nebraska symposium on motivation, vol. 38, pp. 199-235. Lincoln, NE: University of Nebraska Press, 1991.

[70] Ames, Carole. “Classrooms: Goals, structures, and student motivation.” Journal of educational psychology 84, no. 3 (1992): 261.

[71] Biggs, John B. “The role of metalearning in study processes.” British journal of educational psychology 55, no. 3 (1985): 185-212.

[72] Ramsden, P. “Learning to Teach in Higher Education”, Routledge, New York (1992).

[73] Barrows, H., and Kelson, A. C. “Problem-Based Learning in Secondary Education and the Problem-Based Learning Institute” (Monograph 1), Problem-Based Learning Institute, Springfield, IL. (1995)

[74] Gallagher, Shelagh A., William J. Stepien, and Hilary Rosenthal. “The effects of problem-based learning on problem solving.” Gifted Child Quarterly 36, no. 4 (1992): 195-200.

[75] Lesgold, Alan, Harriet Rubinson, Paul Feltovich, Robert Glaser, Dale Klopfer, and Yen Wang. “Expertise in a complex skill: Diagnosing x-ray pictures.” (1988).

[76] Novick, Laura R., and Cindy E. Hmelo. “Transferring symbolic representations across nonisomorphic problems.” Journal of Experimental Psychology: Learning, Memory, and Cognition 20, no. 6 (1994): 1296.

[77] Chi, Michelene TH, Nicholas De Leeuw, Mei-Hung Chiu, and Christian LaVancher. “Eliciting self-explanations improves understanding.” Cognitive science 18, no. 3 (1994): 439-477.

[78] http://www.slideshare.net/TamaraCarletonPhD/playbook-for-strategic-foresight-and-innovation-us

[79] Savin-Baden, M., 2000, Problem-Based Learning in Higher Education: Untold Stories, The Society for Research into Higher Education and Open University Press, Buckingham, UK, 126 and 124]

[80] Hmelo-Silver, C. E., and H. S. Barrows. “Facilitating collaborative ways of knowing.” Manuscript submitted for publication (2003).

[81] Hmelo-Silver, Cindy E. “Collaborative ways of knowing: Issues in facilitation.” In Proceedings of the Conference on Computer Support for Collaborative Learning: Foundations for a CSCL Community, pp. 199-208. International Society of the Learning Sciences, 2002.

[82] Koschmann, Timothy D., A. C. Myers, PAUL J. Feltovich, and Howard S.

Barrows. “Using technology to assist in realizing effective learning and instruction: A principled approach to the use of computers in collaborative learning.” The journal of the learning sciences 3, no. 3 (1994): 227-264.

[83] Hmelo-Silver, C. E. “Knowledge recycling: Crisscrossing the landscape of educational psychology in a problem-based learning course for preservice teachers.” Journal on Excellence in College Teaching 11, no. 28 (2000): 3.

[84] Dahlgren, M. Abrandt, and Lars-Ove Dahlgren. “Portraits of PBL: Students’ experiences of the characteristics of problem-based learning in physiotherapy, computer engineering and psychology.” Instructional Science 30.2 (2002): 111-127.

[85] Evensen, Dorothy H. “Observing self-directed learners in a problem-based learning context: Two case studies.” Problem-based learning: A research perspective on learning interactions (2000): 263-297.

[86] Evensen, Dorothy H., Jill D. Salisbury-Glennon, and Jerry Glenn. “A qualitative study of six medical students in a problem-based curriculum: Toward a situated model of self-regulation.” Journal of Educational Psychology 93.4 (2001): 659.

[87] Ertmer, Peggy A., Timothy J. Newby, and Maureen MacDougall. “Students’ responses and approaches to case-based instruction: The role of reflective self-regulation.” American Educational Research Journal 33.3 (1996): 719-752.

[88] Derry, Sharon J., et al. “Fostering students’ statistical and scientific thinking: Lessons learned from an innovative college course.” American Educational Research Journal 37.3 (2000): 747-773.

[89] Albanese, Mark A., and Susan Mitchell. “Problem-based learning: A review of literature on its outcomes and implementation issues.” Academic medicine 68.1 (1993): 52-81.

[90] Vernon, David T., and Robert L. Blake. “Does problem-based learning work? A meta-analysis of evaluative research.” Academic medicine 68.7 (1993): 550-63.

[91] Kilpatrick, W. H. “The project method.” Teach. Coll. Rec. 19: 319–335, 1918

[92] Dewey, J. Experience and education. Macmillan, New York. 1937

[93] Hmelo, Cindy E., and Mark Guzdial. “Of black and glass boxes: Scaffolding for doing and learning.” Proceedings of the 1996 international conference on Learning sciences. International Society of the Learning Sciences, 1996.

[94] Bernard C.K. Choia and Anita W.P. Pak, “Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiviness” Clin Invest Med, vol. 29, no 6, pp. 351-364, 2006

[95] Klein, J.T. , “Interdisciplinarity: History, Theory, and Practice” Detroit, Mich: Wayne State University Press, 1990

[96] K. Huutoniemi, J.T. Klein, H. Bruun, J. Hukkinen,“Analyzing interdisciplinarity: Typology and indicators”, Elsevier, 2009

[97] P. Rosenfield, “The Potential of Transdisciplinary research for sustaining and extending linkages between the health and social sciences”, Soc. Sci. Med., Vol. 35 35, No 11. Pp 1343-1357, 1992

[98] Bernard C.K. Choia and Anita W.P. Pak, “Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 2. Promotors, barriers, and strategies of enhancement” Clin Invest Med, vol. 30, no 6, pp. 224-232, 2007

[99] Bernard C.K. Choia and Anita W.P. Pak, “Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 3. Discipline, inter-discipline distance, and selection of discipline” Clin Invest Med, vol. 31, no 1, pp. 41-48, 2008

[100] B. G. Glaser, A. L. Strauss, The Discovery of Grounded Theory: Strategies for Qualitative Research, 1967

[101] Leifer, Larry J., and Martin Steinert. “Dancing with ambiguity: Causality behavior, design thinking, and triple-loop-learning.” Information, Knowledge, Systems Management 10.1 (2011): 151-173.

[102] Biggs, John, and Catherine Tang. “Teaching for quality learning at university”. McGraw-Hill International, 2011.

[103] Assadourian, Erik. “State of the World 2010: Transforming Cultures: From Consumerism to Sustainability (State of the World)”. Eds. Linda Starke, and Lisa Mastny. WW Norton & Company, 2010. p. 75-79.

[104] Carleton T., Cockayne W., and Tahvanainen A.. “Playbook for Strategic foresight and innovation”, 2013. [online] Available at: http://www.lut.fi/web/en/playbook-for-strategic-foresight-and-innovation

[105] Raduma, W., Master Thesis “Search for Best Practice in Education: Mechanical Engineering in Aalto University”, 2012. Aalto University.

8 Appendices

Appendix 1: Interview Questions and Intentions (original)

Mitä teet nykyään? Milloin kävit kurssin ja mikä oli projektisi aihe? Millainen on sinun nykyinen arkipäivä? Mikä on intohimosi? (Jäänmurtajakysymyksiä, yritä saada paineettomasti puhumaan itsestään. Epämuodollista taustajuttua.)

Vertaa ME310:tä nykyiseen elämääsi, mistä pidät mistä et?
Mitä ME310läisyys merkitsee(/si?) sinulle?
Kuvaile omaa kurssikokemustasi muutamalla sanalla? Kerro joku tarina kurssilta, joka kuvaa kurssin henkeä, tai kuvastaa oppimiskokemusta?
Millaisia odotuksia suhun kohdistui? “Millaista on olla hyvä 310läinen?”
Miten teitä arvioitiin kurssin aikana?
Mihin käytit eniten aikaasi projektin/vuoden aikana? Mikä toi lisätyötä projektiin?
Isoin kommunikaatiohaaste, miten ratkaisit sen?
Mitä pidät tärkeimpinä tiimikavereiden ominaisuuksina? Miksi?
Millaisiin ihmisiin luotat työelämässä?
Mitä on tärkeintä päätöksenteossa? / Rupesitko tekemään asioita eri tavalla kurssin jälkeen?
Jos vertaat itseäsi nykyisiin kolleegoihisi, huomaatko jotain eroa sinun ja heidän välillä ME310 kurssin takia?
Mitä hyötyä tai haittaa on työskennellessä poikkitieteellisessä ja monikansallisessa tiimissä verrattuna homogeenisen tiimin suoritukseen?
Voitko kertoa tarinan, kun olitte kurssin aikana äärirajoillanne? / tippingpoint? (voitko kertoa millainen päivä se oli?)
Millaisia toimenpiteitä teet projektin jälkeen nykyään?
Voitko kertoa tarinan jostain isosta/mieleenjääneestä epäonnistumisestasi? Mitä opit?
Miten opit tärkeimmän oppisi kurssilta? (mistä olit eniten ja vähiten innoissasi?)
Muuttuiko suhtautumisesi yrittäjyyteen kurssin jälkeen?
Mitkä kurssin opit on sellaisia, mitkä vieläkin kantaa?
Mitä taiteelllista/insinööriyttä/kaupallista(omaa alaa/ammatillista) opit kurssin aikana?
Millainen on sinun määritelmäsi prototyypille/proton tarkoitus? Käytätkö nykyisessä työssäsi?
Miten kehittäisit kurssia omien kokemusten perusteella työelämästä?
Mitä kertoisit hakeville opiskelijoille kurssista

Appendix 2: Interview Questions and Intentions (in English)

What do you do nowadays? When did you take the course and what was your project? How is your daily life currently? What are you passionate about? (purpose: icebreakers, getting the interviewee relaxed, Informal background knowledge.)
Compare your ME310 year to your present life, what do you like, and what not?
What does it mean to be a ME310er for you?

Describe your own course experience with couple of words? Tell a story from the course that would describe the spirit of the course or reflects the learning experience?

What kind of expectations did you face? What does it mean to be a good ME310er?

How you were assessed during the course?

How did you mostly use your time during the course? What brought more work than intended to the project?

What was your biggest communication challenge and how did you solve it?

What do you think is the most important characteristics of your team members?

Why?

What kind of persons you trust in your working life?

What is the most important in decision-making? Did you start doing something differently after the course regarding the decision-making?

If you compare yourself to your present colleagues, do you notice any differences between yourself and them that would originate from your ME310 course?

What would you see the benefits or disadvantages of working in a interdisciplinary team comparing the performance to a homogenic team's performance.
Could you tell a story when you were at your extremities? When was the tipping point? Could you describe that day?

What kind of after care you do after any kinds of projects nowadays?
Could you tell a story about your big/memorable fail during the course? What did you learn?

How did you learn your most important learning? About what you were the most and the least interested during the course?

Did you change your attitude towards the entrepreneurship on the course?

What were the learnings of the course that you still carry with you?

What design/engineer/business skills you learner during the course?

What is your definition to a prototype? What is the purpose of a prototype? Do you use prototypes in your current work?

How would you develop the course further from your experiences from the working life?

What would you tell to prospective students after your experiences?

Appendix 3: Course Description in Oodi

Mechanical Engineering 310 (ME310) is an interdisciplinary, project-based course for Master-level students from all Aalto schools*, and represents a true integration of engineering, business and design disciplines. Originally created at Stanford University, the course has operated continuously for over forty years and Aalto has maintained this intimate relationship with Stanford through ME310 for nearly a decade.

Over nine demanding months, students learn and apply the Stanford/IDEO design process in product development to prototype, test and iterate to solve real world design challenges for multinational corporate sponsors. Originally created to provide engineering students with real life engineering challenges, the course has shifted from practical engineering experience, to design of mechatronic systems, to design innovation, global collaboration and entrepreneurship. Plus, a high premium is placed on community building and networking amongst ME310 students, alumni and faculty.

ME310 is all hands-on, all the time. Also, each team in ME310 pairs with another team from a foreign university to jointly solve the proposed design challenge. These partnerships add diversity to the project teams and give students the opportunity to experience true international collaboration – an essential skill required in this highly globalized world.

All teams in ME310 typically start their projects at Stanford University where they participate in a design thinking kick-off workshop and experience the entrepreneurial culture of Silicon Valley. Final proof-of-concept prototypes are typically presented at the Stanford Design EXPE each June in California.

ME310 in Finland is based at the Aalto Design Factory. The course schedule mirrors Stanford's teaching calendar: Fall period (September – December), Winter period (January – March) and Spring period (April – June). The course language is English. Teaching is supported by Teaching Assistants who are usually ME310 alumni.

Appendix 4: Demographics of the Interviewed Alumni

Class/Year	TA year	Discipline or Major/Minor
2012-2013		Industrial Engineer
2007-2008	2009-2010	Product Development/Lightweight Structures
2007-2008	2009-2011	Producing/Product Development
2008-2009		Industrial Engineer/Media technology
2009-2010		Media Technology/Product development
2005-2006	2006-2007	Geography business/IDBM
2008-2009		BIZ
2006-2007		IDBM/Forest technology
2006-2007		Work Psychology/ME310
2012-2013		Industrial Design
2012-2013		IDBM
2009-2010	2012-2013	BIZ
2012-2013		Product Development/Marketing
2010-2011		ENG
2010-2011		ARTS
2010-2011	2012-2013	BIZ
2009-2010	2010-2011	ME310/IDBM